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Rachel A. Caldwell

University of Montana - Missoula

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ECOLOGICAL STATUS OF BLACK-TAILED PRAIRIE DOGS ON BOULDER,
COLORADO OPEN SPACE AND MOUNTAIN PARKS LAND: AN ANALYSIS OF
SELECT INDICATORS

By

RACHEL ALISA CALDWELL

English and Writing, Southern Oregon University, Ashland, Oregon 2010

Professional Paper

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Approved by:

Sandy Ross, Dean of The Graduate School
Graduate School

Len Broberg, Chair
College of Humanities and Sciences

Dan Spencer
College of Humanities and Sciences

Brady Allred
College of Forestry and Conservation

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Ecological status of black-tailed prairie dogs on Boulder, Colorado Open Space and Mountain Parks land: An analysis of select indicators

Chairperson: Len Broberg

Black-tailed prairie dogs (*Cynomys ludovicianus*) are ecosystem regulators, significantly influencing the surrounding ecosystem. On Boulder County, Colorado Open Space and Mountain Parks land, and throughout their range, prairie dogs affect a number of ecological functions including plant dynamics and associated animals. The ability of prairie dogs to promote the wellbeing of associated plant and animal species depends on the condition of prairie dog populations. One way to evaluate the current condition of prairie dogs and predict their future impact on the ecosystem is to evaluate the status of prairie dogs in relation to specific indicators. I address the ecological status of black-tailed prairie dogs on Open Space and Mountain Parks land based on seven selected indicators, encompassing prairie dog living dynamics, associated plant dynamics, and associated animals. Based on available data, I analyze six indicators. I then make management recommendations based on my findings. Future management should consider the ability of prairie dogs to persist in a manner that benefits prairie dog populations and, by association, other native species and ecological functions. Management must also consider the impact and influence of human development on prairie habitat within open space land, and the potential for collaborative management to sustain prairie dog populations and encourage whole ecosystem health. Failure to manage prairie dogs for the health of the prairie ecosystem could result in the decline of prairie dogs, as well as a host of functions and associated species.

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INTRODUCTION

In the United States, prairie dogs have existed throughout the Great Plains region, and once occupied as many as 100 million acres. Today, they are found on less than 2 percent of their historic range (Lybecker 2002). This significant reduction in habitat is due primarily to urbanization, fragmentation, agriculture and grazing, disease, and poisoning (Lybecker 2002). The loss in prairie dog habitat is of increasing concern as ecologists evaluate the role prairie dogs may play in ecosystem function. As prairie dog populations decline in response to habitat loss, the need to understand their ecological significance becomes increasingly important.

Although there is not agreement among scientists on whether prairie dogs qualify as a keystone species¹, there is consensus that prairie dogs are “ecosystem regulators” (Miller 1994). Their presence affects the plant productivity, community dynamics, and nutrient cycling within an ecosystem (Stapp 1998). Negative effects have been observed in areas where they have been removed, including a decline in available soil nutrients (Stapp 1998). Other species, such as burrowing owls and black-footed ferrets, also require the presence of prairie dogs for their own survival (Stapp 1998). Therefore, it is important when managing a prairie ecosystem where prairie dogs occur to understand the relationship between prairie dogs and their surrounding landscape, the plants found within their habitat, and the animals that closely relate to prairie dogs. This ecosystem-wide understanding is the foundation of productive prairie management.

¹ Consumers that have a significant effect that is disproportionately large relative to their abundance, on communities and ecosystems. Uniquely, the strong effects of keystone species on their interacting species exert extensive influence, often indirectly, on the structure and dynamics of communities and ecosystems.

Recognizing the ecological significance of prairie dogs, the city of Boulder has developed comprehensive management plans to guide management of the region's diverse ecosystems. The City of Boulder Open Space and Mountain Parks (OSMP) manages prairie dogs based on parameters defined within the Grassland Ecosystem Management Plan (Grassland Plan 2010). The Grassland Plan "proposes specific on-the-ground management actions, public policies and lands & water acquisition priorities to conserve the ecological values of Open Space & Mountain Park's grasslands" (OSMP 2010). Ecological evaluation is critical because each year OSMP devotes extensive resources—both time and money—to prairie dog management. Although OSMP regularly assesses specific goals and strategies outlined in the Grassland Plan, it is important to take a closer look at the status of prairie dogs to understand what ecological state these goals and strategies have led to. This knowledge can help inform more informed and sustainable management strategies.

PURPOSE

Through this study I seek to understand the status of prairie dogs on open space land, and how prairie dog management affects species-ecosystem relationships. The paper evaluates the current status of prairie dog living dynamics, as well as the relationships between prairie dogs and associated plants and animals, on open space land, and what changes to management OSMP can make in order to improve prairie dogs' status.

The study begins with a review of prairie dog living dynamics, the relationship between prairie dogs and plant dynamics, and the relationship between prairie dogs and three associated species that have been determined to be significantly related to prairie dogs

and significant indicators of ecosystem health within their range. This data guides the formation of a matrix of elements that are analyzed in the proceeding sections:

1. Colony density
2. Dispersal
3. Colony size
4. Plant dynamics
5. Burrowing owls
6. Black-footed ferrets
7. Ferruginous hawks

These elements guide my evaluation of prairie dogs' ecological value on open space land. In the Methods section, I examine each element individually. I identify why each element should be considered in an evaluation of the ecological value of prairie dogs, and whether there is sufficient existing data to analyze prairie dogs' value in relation to each element. In the Analysis section, I introduce the analytical framework being used to evaluate prairie dogs' ecological value in conjunction with each element. I then proceed with my analysis of the elements with sufficient data to support an analysis. Finally, I conclude with a Recommendations section, where I synthesize my findings and make recommendations to OSMP on adjusting current management policies to increase the ecological value of prairie dogs and their associates on open space land.

ECOLOGY

LIVING DYNAMICS

Prairie dog population and habitat dynamics—including density, dispersal, habitat fragmentation, and size—are key factors to evaluate in any analysis of prairie dogs' effects within colonies and their environment. Prairie dogs' multifaceted, carefully crafted living systems affect breeding, predation, and survival, as well as ecosystem-wide factors. This section examines density, dispersal, fragmentation, and size from a broad perspective, exploring how each in turn influences natural functions across a broad scale, from the individual prairie dog to the surrounding ecosystem.

Density

It is important to evaluate the density of prairie dogs in active colonies when analyzing how prairie dogs affect grassland structure and function. This is because “increase in burrow density may be the most significant effect of prairie dogs in shortgrass steppe” (Stapp 1998:1256), and may help predict successful restoration efforts by providing valuable guiding data (Knopf et al. 2004). Prairie dog density affects a number of ecosystem processes, including soil mixing, primary production of plants, plant and animal diversity, and landscape heterogeneity (Antolin et al. 2007). As prairie dog populations become more dense, the cumulative effects of those animals has a greater effect on these factors, leading to greater vegetative loss and bare ground cover, more soil mixing, and a greater abundance of animals that associate with prairie dogs, including commensal species and predators.

Prairie dog densities vary over time based on climate, forage, predation, and disease (Hoogland 2006). However, average prairie dog densities can be drawn from a number of studies to help inform ideal densities in management practices. In their paper on the ecological consequences of prairie dog disturbances, Detling and Whicker stated that in unmanaged colonies that are allowed to naturally expand, prairie dog densities average 10 to 55 animals/ha (Detling and Whicker 1988). Hoogland estimates that average prairie dog densities, as might be found in a natural, unconstrained setting, average around 25 adults and yearlings per ha (10 per acre) (Hoogland 2006), an estimate that falls well within Detling and Whicker's range. Another study used specific density-estimation techniques to compare prairie dog densities in two areas: one fragmented area in the Denver suburbs, and one unfragmented, effectively unbounded area within the Pawnee National Grassland. The study found that densities in two sites surveyed at the urban area ranged from approximately 113/ha to 116/ha, while mean density on two sites in Pawnee National Grassland averaged 26/ha (Magle et al. 2006). These studies all point to a trending range of densities in naturally occurring ecosystems, with results all falling within Detling and Whicker's range of 10 to 55/ha.

While few studies have closely analyzed the average density of prairie dogs on active colonies in Boulder County, two independent studies have been conducted that provide insight on density trends on open space land. In 2002, Whitney C. Johnson submitted a master's thesis titled, "*Landscape and Community Characteristics of Black-tailed Prairie Dog Colonies.*" As part of this paper, Johnson conducted a study of the average density of prairie dogs on active colonies in Boulder County. Johnson sampled 22 colonies in 2000 and 2001. The study found that density in those two years ranged between 32 and

120 prairie dogs/ha, with a mean density of 68 prairie dogs/ha. A separate study published by Sackett et al. (2011) in 2012 used visual counts to estimate population densities on 10 active prairie dog colonies in Boulder County in the years 2003 and 2004 (Sackett et al. 2011). Density ranged from 11 prairie dogs/ha to 64 prairie dogs/ha, with a mean density of 29/ha. Although the method of data collection was informal and based on visual estimates alone, the estimates do provide further evidence regarding average population densities in Boulder County.

Dispersal

Dispersal—moving from one territory to another—helps control populations in any one area, and facilitates the flow of genes to prevent inbreeding. Prairie dogs commonly disperse between two and three kilometers, and up to six kilometers, from their natal colony (Hoogland 2006). Complexes typically are no more than six kilometers apart, to aid in dispersal. Because of this dispersal range, the distance between colonies is an important factor. Prairie dogs disperse individually rather than in groups, and only disperse onto established colonies (Hoogland 2006). That is, a dispersing male will not disperse onto an uncolonized area and begin a colony. Although most females spend their lives in the territory where they were born (Hoogland 2006), females are just as likely as males to disperse within a colony (Hoogland 2006).

Reproduction is the key driver of natal dispersal. “Young males disperse from natal territories before reaching sexual maturity as a mechanism to avoid inbreeding with mothers, aunts, or sisters. They disperse every two years, because females become fertile in their second year (Hoogland 2006:25).” Therefore, this dispersal pattern ensures that

males will not have the opportunity to mate with their offspring. Dispersal opportunities also influence breeding occurrence: in some instances, a female prairie dog may not become sexually receptive if the only male on her colony is a relative (Hoogland 2006).

Dispersal of individuals from a designated area to other breeding locations affects the genetic and demographic structure of populations (Knopf and Samson 1994). Small populations can't contain the genetic variation that is present across a species' range. Furthermore, reduced variation makes populations vulnerable to extinction because animals can't adapt to changing conditions; increases inbreeding which limits animals' ability to defend against disease, parasites, and changes; and leads to birth defects (Hoogland 2006). Because only five percent of prairie dog mating involves extreme inbreeding, dispersal is a proven, effective mechanism for avoiding inbreeding and improving breeding likelihood (Hoogland 2006) and is therefore an important factor for the overall vitality of the species.

Not only is distance to other colonies important, but also access to those colonies is critical. Colonies and individual prairie dogs must be able to organically shift and disperse. Dispersal opportunities are limited in increasingly fragmented habitat schemes, which may limit reproductive opportunities for prairie dogs. Prairie dogs' movement creates a larger functional map than just the areas of active prairie dog colonies. It includes the areas between colonies that prairie dogs must utilize and cross in order to disperse (Knopf and Samson 1994). Under natural circumstances, natal dispersal inherently increases mortality risk. This is due in part to lack of communal predator

watch, exposure to predators without the safety of a burrow to retreat to, and potentially from natural elements.

However, urban development, roads, agricultural land, bodies of water, and other obstructions all may separate prairie dog habitats on open space land. These obstructions all raise the risk of mortality from dispersal. According to Boulder County Parks and Open Space (BCPOS), “dispersal across fragmented habitat as it exists in Boulder County may subject [prairie dogs] to higher levels of mortality from vehicles or predators than might be found in contiguous prairie” (PDHE 2012:29). Studies have not confirmed that habitat fragmentation directly leads to increased density due to limited dispersal opportunities. However, BCPOS asserts that the boundedness and increased density found in Boulder County—whatever the cause—may reverse the positive impacts to associated soil, plants, and animals in the grassland. This can have a number of negative effects, from increased erosion, to expansion of weeds and non-native plant species, and to overall degradation of the grassland habitat (PDHE 2012). This issue relates back to the issue of increased density within urban colonies, and thus helps further prove how significant density is as an ecological indicator for colony and ecosystem health.

Size

Colony size—the acreage or total area of a colony—significantly affects ecosystem dynamics. Many advantages can be derived from large colonies, benefitting both prairie dogs and associated species. It is difficult to find data reporting an accepted definition of what constitutes a “small” versus “large” colony; this distinction is not defined within the ecological community. However, independent studies help provide some parameters.

Johnson and Collinge reported average colony size in Boulder County of .05 to 100 ha, averaging 8 ha (Johnson and Collinge 2004). Clark et al. cited colonies under 10 ha as “small”, without further definition (Clark et al. 1982:574). For the purpose of this analysis I use this definition for what constitutes a “small” colony.

Small colonies, particularly those that are new, are unlikely to persist if they are too isolated (Hoogland 2006). This may be due to limited breeding options, as discussed above, or an increasing limitation on available forage, as native grasses give way to non-native plants and woody shrubs. Colony size also provides safety from predation (Hoogland 2006). With larger colonies comes better predation detection. According to Hoogland, “...in larger colonies, the collective time spent scanning by all colony members is greater. Consequentially, individuals in large colonies detect enemies more quickly and more often than do isolates and individuals in smaller colonies” (Hoogland 2006:13). Predation decreases with more eyes and ears available to watch for potential threats and illicit warning calls.

Furthermore, colony size has significant effects on a number of associated species, including endangered black-footed ferrets, which are discussed at greater length below. Many species require prairie dog colonies of a certain size in order to persist, for safety reasons, for resources including burrows and forage, and for the predation opportunities that large colonies provides. One study found that as colony size increased, the number of vertebrate species observed on colony also increased (Clark et al. 1982).

It should be noted that while the emphasis in literature is placed on increasing colony size, there is a limit to the benefits gained from increasing colony size. Colonies that become too large may be at an increased risk of succumbing to a plague outbreak (Johnson and Collinge 2004). Large colonies tend to attract a higher number of associated species, as Clark et al. found, which increases the risk of disease entering the colony. Once disease begins to infect the colony, it can move quickly, eradicating most, if not all, of the prairie dogs within that colony. Smaller colonies, on the other hand, are less likely to experience disease, and if plague does enter the colony, the total species loss will be far less significant.

PLANT DYNAMICS

The Colorado Front Range is home to a number of ecosystems, from coniferous forest; to short, mid, and tall grasslands; to wetlands and riparian areas. In Boulder County, prairie dogs are found on shortgrass and mixedgrass prairie (Collinge et al. 2005), in areas defined by OSMP as the Mixedgrass Prairie Mosaic. Prairie dogs found in the Mixedgrass Prairie Mosaic affect and alter plant dynamics in a number of ways. Prairie dogs disturb grasslands by burrowing, grazing, and clipping, and also create large patches of altered vegetation in the landscape (Detling and Whicker 1988). These effects in turn influence the presence of both native and nonnative species within the ecosystem, thereby affecting plant diversity within active colonies. Below, I explore two ways in which prairie dogs alter plant dynamics: grazing and clipping.

Grazing is one of the most significant disturbances prairie dogs have on grasslands. Grazing is a natural disturbance, but not all grazing is the same. Although intensive

grazing from any species will significantly alter plant dynamics, no other species has such a significant—and therefore unique—effect on grasslands (Biggins et al. 2008). Grazing reduces overall grass cover, leaving less forage available for other herbivores. Grazing also, however, can increase the nutrient content in plants. One explanation is that as some plants are grazed, they send nutrients aboveground in order to maximize photosynthetic opportunities and increase growth. Another hypothesis is that because new growth is younger, and plants lose nitrogen concentration over time, the new growth is comparably more nutritious than prior, older growth grasses (Detling and Whicker 1988). Plants that are heavily grazed by prairie dogs such that overall biomass is lower than it would be in the absence of prairie dogs may have higher nutritional value. Clipping is another key disturbance that prairie dogs impose on their surroundings. Prairie dogs mow tall plants that are found on the colony, using their teeth to clip the plants at the base. Clipping improves visibility and therefore improves predator detection (Grassland Plan 2010).

However, excessive grazing and clipping in one area can significantly reduce native plant cover and increase bare ground, making it possible for nonnative plants to invade the community (Grassland Plan 2010). Increase in bare ground is related to the higher levels of weed cover typically associated with long-term prairie dog occupancy (Grassland Plan 2010). As prairie dogs consume and clip vegetation over time, grasses become weak at their roots and lose their ability to compete with other plants, including nonnative plants that are able to take advantage of the increase in soil nutrients and available sunlight (Hoogland 2006). Therefore plant dynamics in a colony relate to dispersal, density, and colony size; colonies that stagnate in one area, lacking the ability to naturally change

shape, size, and density due to boundedness and fragmentation, may cause an increase in nonnative plant cover on colonies.

In these ways, prairie dogs significantly affect the immediate and surrounding vegetation. Entire ecosystem processes can change over time due to the balance between prairie dog activity and plant dynamics. One study in Wind Cave National Park studied percentage of forb, bare ground, grass, and litter cover over time on active prairie dog colonies. The authors found that five years after colonization, forb and bare ground cover had increased, while grass and litter cover had decreased (Hoogland 2006). This study demonstrates how plant dynamics fluctuate naturally over time, which is an important part of long-term ecosystem health. However, as the ecosystem naturally cycles through these stages, nonnative species can take root and alter plant dynamics and the integrity of the surrounding ecosystem.

ASSOCIATED SPECIES

Managing and conserving prairie dogs is important not only for the continuation of the species, but also for the continuation of a number of associated species. Miller and Reading (1994) stated that approximately 170 vertebrate species rely at least on some level on prairie dog activity for survival. Although Stapp argues that the implications of this statement are misleading, and may imply that all of these species will die off without prairie dogs (Stapp 1998), the fact remains that nearly 200 animal species do utilize, at varying levels, the presence of prairie dogs on the grassland ecosystem.

Hoogland identified key associated species based on burrow use and predation. Major

mammalian predators include American badgers, bobcats, coyotes, long-tailed weasels, black-footed ferrets, and humans. Other mammals that may prey on prairie dogs include swift foxes, red foxes, common gray foxes, and mountain lions. Reptile predators include bull snakes and rattlesnakes. Avian predators include golden eagles, northern goshawks, northern harriers, peregrine falcons, prairie falcons, Cooper's hawks, ferruginous hawks, red-tailed hawks, and several others (Hoogland 2006). In addition to serving as prey, prairie dogs create burrows for other associated species (Biggins et al. 2008). Burrows provide refuge for American badgers, black-footed ferrets, burrowing owls, prairie rattlesnakes, and tiger salamanders (Hoogland 2006).

I will evaluate three species as they relate to prairie dogs on open space land: black-footed ferrets, burrowing owls, and ferruginous hawks. With over 170 associated species, careful analysis must focus on specific species rather than the overall composition of all potential associated species. Further research or similar studies could explore prairie dogs' relationship with a number of other associated species which may lead to different conclusions from those I arrive at in regard to the three species I have chosen to analyze. The three species chosen are traditionally present in Colorado mixed grass prairies and have significant connections with prairie dogs, as well as being species of conservation concern in their own right. Black-footed ferrets are obligate predators of prairie dogs, and are arguably the species most closely associated with prairie dogs. Burrowing owls benefit from occupying prairie dog colonies in a number of ways, and currently nest on open space land. Ferruginous hawks winter on open space, and while they do not currently nest on open space the region is within potential year-round habitat for the species. Although these three species are far from the only three species on open space

land that are associated with prairie dogs, they are closely associated and in different ways—in an obligate capacity, in a commensal capacity, and in a predatory capacity. These three species represent the variety of associations species have with prairie dogs.

Burrowing Owls

Burrowing owls are closely associated with prairie dogs because of the survival benefits that owls gain by occupying prairie dog colonies. Owls benefit from prairie dogs in three key ways: 1) prey detection is increased on colonies, 2) burrowing owls utilize prairie dog burrows for nesting, and 3) prairie dog alarm calls alert owls to predators (Hoogland 2006:57).

Prairie dog colony presence and colony size are two key ecological factors that affect burrowing owls. The abundance of owls on a given area may be determined by the presence of prairie dogs (Desmond et al. 1995). Regional declines in burrowing owls have been linked to habitat loss and degradation (PDHE 2012), and because most owls nest in prairie dog burrows, prairie dog habitat loss is correlated with burrowing owl habitat loss. In one study conducted in Oklahoma, prairie dog colonies were the only areas where owls established nesting colonies (Butts and Lewis 1982).

Beyond the mere presence of prairie dogs, the size of prairie dog colonies also affects burrowing owls. In a study on the spatial patterns of burrowing owl nests within prairie dog towns, Desmond et al. (1995) found that owls prefer larger towns (>35ha) to smaller towns (<35ha). Nest availability is a main reason for this selection. In their study, Butts and Lewis noted that in smaller prairie dog towns owl nests were denser but more

randomly distributed, due to habitat shortage and lack of ability to select nesting areas more prudently. In larger colonies (>35ha), owls nest in clumps, but those nests are further from each other than nests are in small colonies, where nest location is random but denser overall. Desmond's study found that average distance between nests in large colonies averaged 125.0m, and in small colonies the distance between nests averaged 105.1m. The authors noted that in some small colonies, owls nested as closely as 11m from each other, but there was not overall nest clumping; that is, the location of all nests was random. The distance between two nests is significant. One study cited by Desmond et al. (1995) found that when nests were located within 110m of one another, one nest was abandoned. Therefore, nesting in clumps but with enough spatial opportunity to make preferable nest location decisions allows owls to naturally nest at ideal distances.

Black-Footed Ferrets

Black-footed ferrets are perhaps more closely associated with prairie dogs than any other species. In fact, Kotliar et al. (1999) designated ferrets as obligately dependent on prairie dogs (Hoogland 2006). Black-footed ferrets were once found throughout the Great Plains and semi-arid grasslands; furthermore, their historical range nearly exactly coincides with the historical range of prairie dogs (Clark and Hillman 1980). In the early part of the 20th century, prairie dogs occupied 41,000,000ha. Based on current knowledge regarding black-footed ferret densities on prairie dog colonies, this could have supported 500,000-1,000,000 black-footed ferrets, if the area was occupied by both species to its full potential (Anderson et al. 1986). Currently, black-footed ferrets are listed as endangered under the Endangered Species Act. In Colorado they are considered critically impaired,

and are classified as “threatened” by the Colorado Division of Wildlife. OSMP considers them a “Special Concern Priority” (Grassland Plan 2010:B-7).

Black-footed ferrets need large-scale, contiguous prairie dog habitat to survive. As much as 800ha of occupied prairie dog habitat may be needed to establish a functioning population of black-footed ferrets that is able to reproduce and persist (Knopf and Samson 1994). A prairie dog complex of this size can support 200 adult black-footed ferrets. A population of 200 black-footed ferrets is a critical conservation threshold because a black-footed ferret population of this size is significantly less likely to suffer from consequences of inbreeding than a smaller black-footed ferret population (Biggins et al. 2007).

Black-footed ferrets were one of prairie dogs’ main historical predators. Black-footed ferrets are the only predator of prairie dogs that relies almost entirely on prairie dogs for their diet (Hoogland 2006). One study found prairie dog remains in 91% of black-footed ferret scat (Clark and Hillman 1980). When black-footed ferrets are present on colonies, there is also a correlated increase in the presence of other predators such as badgers, bobcats, and hawks, all of which prey on both ferrets and prairie dogs (Anderson et al. 1986). Therefore, the presence of black-footed ferrets may lead to an increase in predators that also prey on prairie dogs, which can help manage prairie dog populations.

Furthermore, prairie dog colony dynamics and spatial distribution also affect black-footed ferrets—prairie dogs determine habitat conditions for black-footed ferrets (Wiens 2008). One study explored the relationship between prairie dogs, black-footed ferrets, and

vegetation dynamics. The authors found that prairie dog distribution likely changes in response to vegetation dynamics and productivity, and black-footed ferrets select for areas with high prairie dog burrow density² (Biggins et al. 2008). The authors concluded that “through management of vegetation we can improve habitat for ferrets by creating large high-density areas” (Biggins et al. 2008:14).

Ferruginous Hawks

Ferruginous hawks are grassland birds whose range encompasses open, rolling prairie throughout the North American Desert and Great Plains regions. According to OSMP the species can be found on open space during the winter, though they are not known to have ever nested in Boulder County (Grassland Plan 2010). The Colorado Front Range falls on the cusp of year-round habitat for ferruginous hawks. Although these birds are secure globally (their range can reach as far north as Canada and as far south as Mexico), Colorado Parks and Wildlife has designated them a “Species of Concern” in Colorado (Colorado Parks and Wildlife 2003).

Mild to heavily grazed areas create ideal habitat for ferruginous hawks, because the lack of cover allows the hawks to easily spot prey. Thus, ferruginous hawks found within the range of prairie dog habitat frequently nest near active prairie dog colonies due to the increased visibility created by prairie dog grazing and clipping. In fact, one study found that ferruginous hawk populations were directly correlated with proximity to the nearest prairie dog colony (Colorado Parks and Wildlife 2003). Not only do prairie dogs facilitate

² Biggins et al. (2008) found that black-footed ferrets preferentially occupied “high density colonies” but did not specify a definition of “high.” The sample colonies where black-footed ferrets were mapped ranged in burrows/ha from 48.9 to 79.4 (for colonies in Montana), with one colony averaging 138.9/ha (in South Dakota).

prey detection for ferruginous hawks, but at least in Colorado, prairie dogs are also one of the hawks' main food sources (Colorado Parks and Wildlife 2003). However, ferruginous hawk diet varies based on location and available prey, and may include ground squirrels, jackrabbits, and other small rodents.

Ferruginous hawks are careful nesters, and are particularly sensitive to disturbances—usually those created by human activity. Disturbances often cause a hawk to temporarily leave its nest, returning after increasing periods of time. Eventually, continued disturbances may cause the hawk to abandon the nest entirely, stranding either eggs or chicks. For this reason, Colorado Parks and Wildlife recommends restricting human activity to within ½ mile of active nests (Colorado Parks and Wildlife 2008). Ferruginous hawks also practice nest fidelity, returning to the same nest site or area for consecutive years. Hawks that abandon their nest due to repeated disturbance may avoid that nest site the following year. Studies have found that this repeated cycle of disturbance and nest abandonment may result in hawks leaving the area permanently (Colorado Parks and Wildlife 2008).

ANALYTICAL FRAMEWORK

In this section I consider the potential for each of the above element as a framework element. I reiterate the significance of each element and demonstrate how it would be evaluated as a framework for analyzing the overall ecological value of prairie dogs on open space land. I then determine whether the element can be applied as a framework element or whether it will be addressed in the Recommendations section, where I illustrate gaps in data and recommend further research.

This framework is based on available information sourced from data gathered by OSMP and outside literature. The framework outlines the methods of analysis for each element, and uses available literature to specify methods for measuring prairie dogs' ecological value in relation to each element, assigning a relative "low value" and "high value" for each element. The value for each element is then determined by comparing data from existing literature to the current condition of prairie dogs and their associates on open space, and applying the results to the framework in order to determine ecological status. The availability of data is the key determinant of the elements included in this framework. Other categories, including those already discussed that are not listed below, could have been considered and applied to this framework, but without data to measure the categories they cannot be applied at this time.

The following steps outline the process of analysis:

1. I establish a set of metrics to gauge the status of the Boulder Open Space prairie dog population in order to navigate the complexity of the topic and bring attention to limitations of knowledge regarding prairie dog ecology on open space land.

2. The metrics are developed by combining available information on prairie dog populations on open space land with data that have defined quantitative or descriptive thresholds described in existing literature.
3. Ideal framework elements that should be analyzed but that lack adequate data are set aside and identified as potential monitoring or research topics OSMP should pursue, if full analysis of prairie dog population health is desired.
4. The analysis is based on comparing OSMP's data on prairie dogs with the thresholds given in the framework, and then combined to provide an overall picture of prairie dog population health on open space land.

LIVING DYNAMICS

Density

Why is it important to consider?

This element is critical because beyond the mere presence of prairie dogs, prairie dog density has perhaps the most significant effect on the surrounding ecosystem. Density can affect plant productivity, native and nonnative plant cover, presence or absence of associated predator and commensal species, and the overall state of the ecosystem (Stapp 1998). Average densities vary based on a number of factors including climate, forage, predation, and disease. However, data referenced in the previous section suggests that in urban areas, density is much higher—as much as 250 times higher—than average densities in unmanaged areas where prairie dogs can move freely. In areas where colonies can expand naturally, densities can occur at levels that are sustainable for the species and ecologically productive. Because of the potential negative effects of increased density in

urban areas, it is important to consider the status and potential implications of increased density when making site-specific and large-scale ecological management decisions.

To analyze this element, one can look at trends in data on the density of prairie dogs on colonies on open space land, and compare it to the data on densities in naturally occurring areas.

Can it be applied as a framework element? Why or why not?

Historically and currently, OSMP does not measure prairie dog densities; rather, OSMP maps the extent of active prairie dog colonies across open space land. Therefore there is little available data on prairie dog density on open space land. However, two independent studies provide some relevant data on average densities in Boulder County. Johnson's thesis work and the estimates collected for the study published by Sackett et al. provide insight into average densities.

Similarities between landscape characteristics may further justify the use of the data provided by Sackett et al. as sufficient for analysis. In 2000 and 2001, two years that Johnson and Collinge collected data on density for their paper "*Landscape Effects on Black-tailed prairie dog colonies*," OSMP recorded that there were 1,788 and 2,347 acres of active prairie dog colonies. In 2003 and 2004, when Sackett et al. gathered data for the paper "*Connectivity of prairie dog colonies in an altered landscape: inferences from analysis of microsatellite DNA variation*," there were 3,223 and 3,320 acres of active prairie dog colonies on open space land. In 2013 and 2014, the last two years for which there is available data on active colonies, there were 3,090 and 3,052 acres of active

prairie dog colonies, respectively. Furthermore, comparing maps of the range of active prairie dog colonies between 2003, 2004, 2013, and 2014 show marked similarities in the distribution of active colonies (*See* Figures 1.0 and 2.0). These parallels support the conclusion drawn by Magle et al. and others: when there is more available habitat, colonies are less dense. Considering this conclusion in light of the analysis at hand, it is reasonable to infer that given the similarities in acres of active colonies between 2003-2004 and 2013-2014, and the similarity in colony distribution, the average density in 2013-2014 is similar to—if not slightly higher (given the slightly higher number of acres of active colonies)—than the average density reported in 2003-2004.

Using the data and justification above, this element can be evaluated as a framework element.

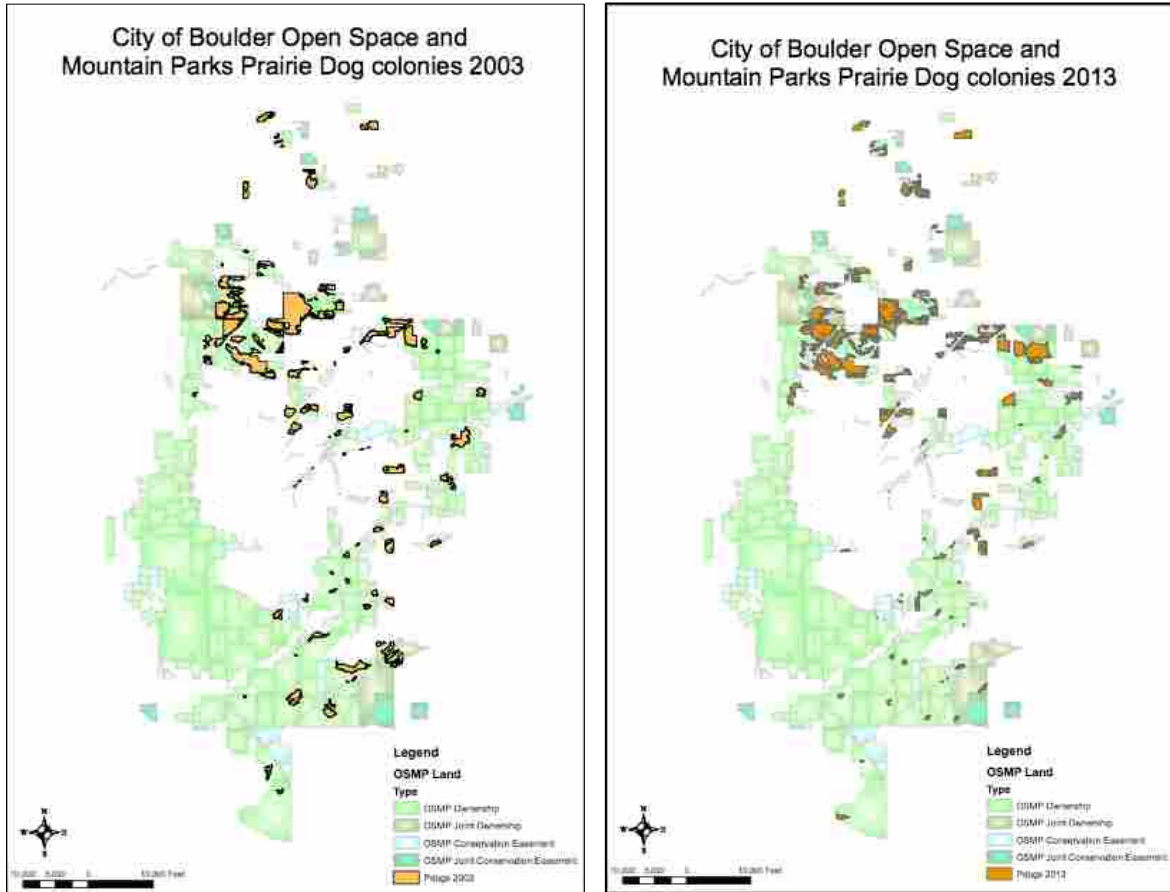


Figure 1.0: Comparison of colony distribution between 2003 and 2013.
(Maps © Open Space and Mountain Parks)

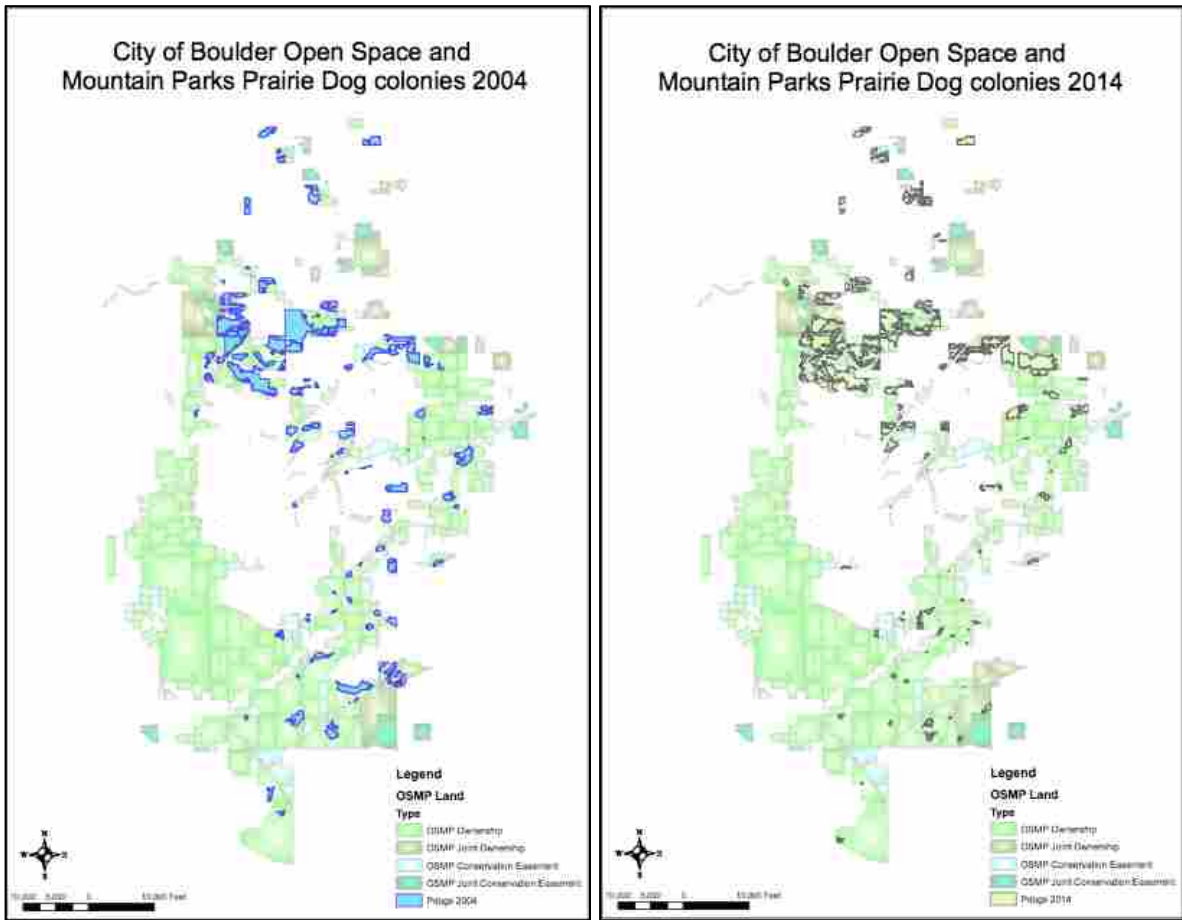


Figure 2.0: Comparison of colony distribution between 2004 and 2014.
 (Maps © Open Space and Mountain Parks)

Dispersal

Why is it important to consider?

Dispersal—the movement from one territory to another—is necessary for the health and vitality of individual prairie dogs and colonies. This essential function allows for genetic variation, lowered density, and stable population dynamics. Male prairie dogs disperse to new territories in order to find genetically unrelated mates. Because the males disperse every two years, long-term success of the prairie dogs within an area depends on both accessible and ample dispersal opportunities.

Prairie dogs typically disperse two to three kilometers, but up to six kilometers, in order to access a new territory for mating purposes. Analyzing dispersal opportunities on open space land will involve evaluating available maps of active prairie dog areas, in order to understand their proximity and whether the locations of active prairie dog colonies could support successful dispersal.

Can it be applied as a framework element? Why or why not?

Working with available maps, as well as knowledge regarding translocation and eradication efforts, provides sufficient data to apply this element to the analytical framework.

Size

Why is it important to consider?

On open space land, a number of associated animals and ecological functions are impacted by active prairie dog colony size. Burrowing owls, ferruginous hawks, and black-footed ferrets—the three individual species evaluated in this document—all require

colonies of a certain size in order to successfully associate with prairie dogs, for predation, burrowing, and nesting opportunities. Without colonies of an adequate size, these animals may not be able to persist on open space land. Plant dynamics are also affected by colony size. When colonies are not large enough to support the colony's prairie dog population, nonnative plant species may invade the area. This dynamic is further discussed in the Plant Dynamics section. These are only a few of the ways that prairie dog colony size influences the surrounding ecosystem on open space land and beyond. When managing prairie habitat, it is therefore critical to understand historical trends and current colony sizes, and consider the impact that colony size has on other facets of the ecosystem.

Can it be applied as a framework? Why or why not?

Since 1996, OSMP has gathered annual data on active colony locations, mapping colonies and totaling the number of actively occupied acres. These data provide valuable information on the location and extent of prairie dog colonies, and help infer long-term trends in colony size and location, as well as the overall extent of prairie dog colonies.

Before evaluating colony size for a given year, it is important to address the limitations of this analysis. Colony boundaries and overall size are constantly shifting due to prairie dog movement, environmental changes, and colony reduction due to plague. This last factor is particularly relevant in the case of colonies on open space land. Since 1996 two significant plague epidemics have eliminated not only the largest colonies on open space land, but entire areas of active prairie dog colonies. In 2005, nearly the entire North Grassland preserve was occupied by large prairie dog colonies; the area contained the

most colonies per acre (*See*: Figure 3.0). However, this area “plagued out” and by 2006, as Figure 3.0 shows, only a handful of critically small colonies remained. This occurred in 2009 in the South Grassland Preserve as well (*See*: Figure 4.0).

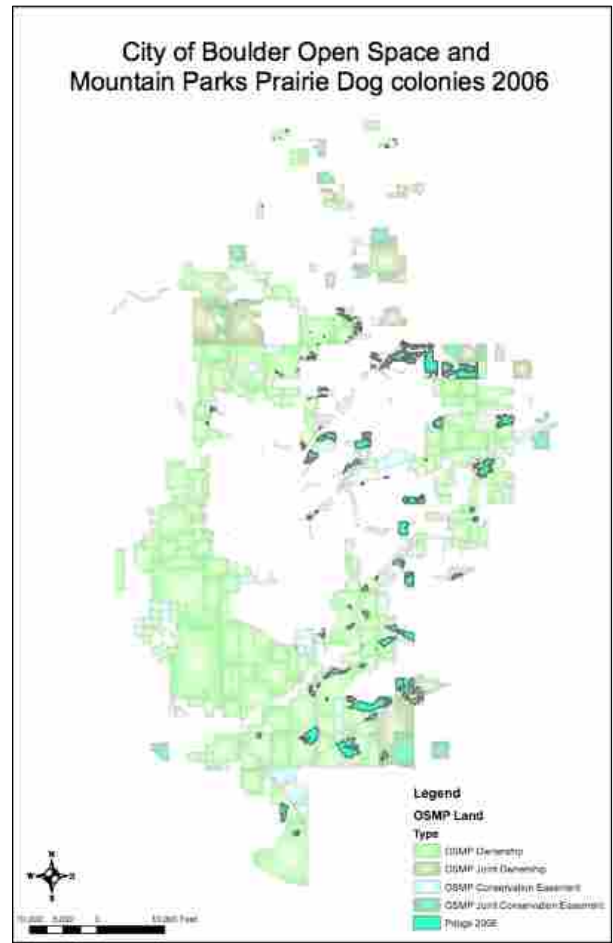
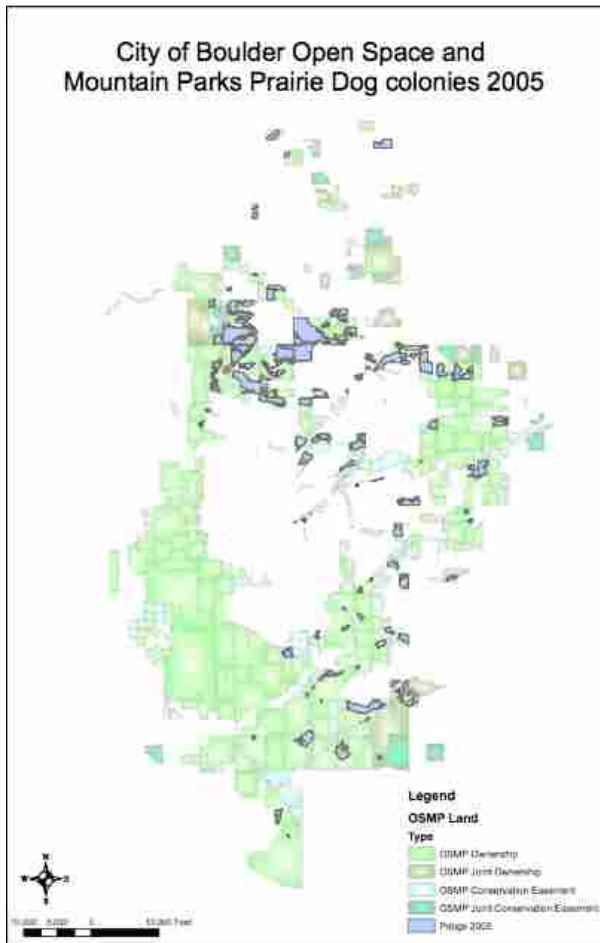


Figure 3.0: Comparison of prairie dog colonies in 2005 and 2006.
(Maps © Open Space and Mountain Parks)

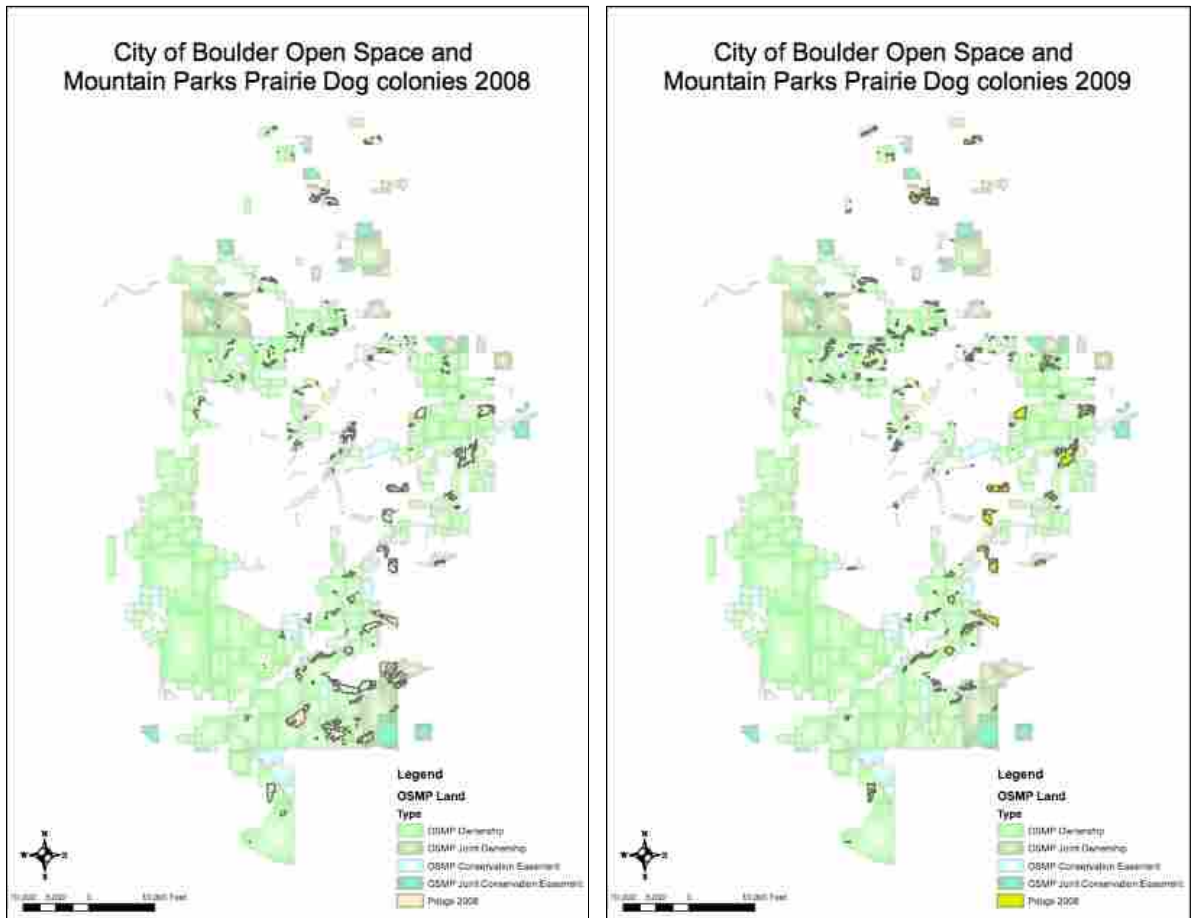


Figure 4.0: Comparison of prairie dog colonies between 2008 and 2009.
(Maps © Open Space and Mountain Parks)

Despite the constantly changing map of colony size and extent, with annual data on colony size collected by OSMP, I can evaluate colony size in a given year, with the recognition that the rating will inherently change annually based on fluctuations caused by plague, shifting environmental conditions, natural prairie dog movement, human-imposed translocation or relocation, or other factors. For the purpose of this analysis I evaluate colony size in 2014 in order to better understand the current state of prairie dogs on open space land, while further discussing the limitation of this analysis based on annual changes in colony size and total extent. Although there is data available on colony size as of March 2015, without a full year's worth of data I cannot analyze this category for the current year.

Because of the importance of colony size for prairie dog persistence, disease management, associated species success, and plant dynamics, this category can be rated by the number of colonies at least 10ha in size. A majority of colonies 10ha or larger will indicate high ecological value.

PLANT DYNAMICS

Why is it important to consider?

Because prairie dogs have a significant effect on plant dynamics, one way to measure their value is to examine percentages of native and nonnative plant cover on active prairie dog colonies. Prairie dogs graze and clip plants on colony; over time, and when density is high or when colonies are severely bounded, these behaviors can reduce native plant cover, allowing nonnative plants to take advantage of the available soil nutrients and bare cover. Nonnative plant species are an issue on open space, and in any landscape context,

because “some non-native plant species displace native vegetation [and] compete directly with native plants for places to grow, nutrients, sunlight and soil moisture” (Grassland Plan 2010:89).

Although OSMP has evaluated native and nonnative plant dynamics within the Mixedgrass Prairie Mosaic (Grassland Plan 2010), which encompasses areas where prairie dog colonies occur on OSMP land, this information has not been analyzed in the context of active prairie dog colonies. Further analysis is needed to evaluate the percentage of nonnative plant cover on active prairie dog colonies on open space land. Long-term analyses of prairie dog density and occupation, as well as plant dynamics on colonies, could help explain how or whether prairie dogs contribute to nonnative plant occurrences within the Mixedgrass Prairie Mosaic

This element would be analyzed by reviewing the percent of native versus nonnative plant cover on active prairie dog colonies, and comparing that data to the percent of native plant and nonnative plant cover off active colonies. This comparison could be adjusted in a number of ways, including by length of time of colonization, grassland type (mixedgrass, shortgrass, etc.), whether prairie dogs had ever occurred on an uncolonized area (and if so, when), and so on. Initially, the first step is to evaluate native and nonnative plant cover on and off colonies, to understand whether native cover increases or decreases on colonies, or whether there is no trend.

Can it be applied as a framework element? Why or why not?

Because there is no known data on native and nonnative plant cover on active prairie dog colonies in Boulder or in any context for open space, and no known comparative data on

native plant cover off active prairie dog colonies, this element cannot be evaluated as a framework. I further discuss this factor in the Recommendations section.

ASSOCIATED SPECIES

One could choose any number of associated species and their current status on prairie dog colonies within open space land to assess the correlated value of prairie dogs. For the purpose of this paper, I chose to analyze three species that are also analyzed at length by OSMP: burrowing owls, black-footed ferrets, and ferruginous hawks. These species are important indicators of prairie dog value because of the mutual effects that they and prairie dogs have on the ecosystem when they thrive in conjunction with one another.

Burrowing Owls

Why is it important to consider?

Burrowing owls have a commensal relationship with prairie dogs, benefitting from them in three key non-predatory ways: using prairie dog burrows as nests, increased prey detection due to thinned ground cover, and increased predator warnings from alert prairie dogs. Because of the close relationship between burrowing owls and prairie dogs, burrowing owl declines have been observed in areas where prairie dogs have been reduced or eradicated. Burrowing owls are currently listed as a species of concern in Colorado (Colorado Parks and Wildlife).

One way to analyze the ecological value of prairie dogs through the current state of burrowing owls is to evaluate the number of active prairie dog colonies on open space land that are at least 35ha as well as the location of burrowing owl nest sites. Although

data is not available on the exact location of burrowing owl nests, OSMP implements annual area closures on parcels of open space land where burrowing owls are observed nesting. Therefore this evaluation is based on the location of nesting closure sites, the approximate size of prairie dog colonies within those closure areas, and the number of colonies across open space land that are .

Can it be applied as a framework element? Why or why not?

With data on the number of colonies $\geq 35/\text{ha}$, the approximate location of prairie dog colonies in 2014, and the location of nest closure areas in 2014, this element can be applied as a framework element.

Black-Footed Ferrets

Why is it important to consider?

This critically endangered prairie species is so dependent upon prairie dogs that when prairie dog populations plummeted 98 percent, ferrets were nearly eradicated as well. Black-footed ferrets require large-scale prairie dog habitat in order to survive. As available prairie dog habitat shrinks, and becomes increasingly fragmented, areas large enough to support a viable population of black-footed ferrets are becoming increasingly rare. However, the presence of black-footed ferrets on prairie dog habitat provides many benefits, including prairie dog population control through consumption and attraction of other species that also prey on both prairie dogs and black-footed ferrets.

Black-footed ferrets are not currently found on open space land. They are listed as endangered at the state (Colorado) and federal level, and are considered a “species of

concern” by OSMP. This element, therefore, could be measured by the mere reintroduction of black-footed ferrets on open space land. However, according to BCPOS, there is not enough suitable habitat to support black-footed ferrets in Boulder, although they have committed to reviewing the potential reintroduction every five years. Another more attainable metric would be to analyze number of prairie dog habitat areas that are 800ha or larger—the extent needed to support a viable black-footed ferret population.

Can it be applied as a framework element? Why or why not?

Currently, there are no black-footed ferrets in Boulder. However, given their proven ecological value and significance in relation to prairie dogs, the absence of black-footed ferrets on open space land should not preclude them from consideration as a potential future framework element. In this case, I will evaluate not the presence of black-footed ferrets, but the potential to support black-footed ferrets. To do so I analyze the extent of available habitat to determine whether there is at least one area large enough within the open space matrix to support a black-footed ferret population. I do so using maps that demonstrate the extent of available prairie dog habitat on open space land. Therefore this element can be applied as a framework element.

Ferruginous Hawks

Why is it important to consider?

Ferruginous hawks are listed as a species of concern in Colorado, though they are considered secure globally. This is partly due to the fact that ferruginous hawks avoid areas near urban or suburban development. In addition to ferruginous hawks’ tendency to

avoid urban areas, loss of prairie dog habitat has also contributed to the absence of ferruginous hawks on open space land. Despite the fact that Boulder Open Space land is within the breeding range of ferruginous hawk, no nesting has been recorded in Boulder County (Grassland Plan 2010). However, given the abundance of prairie dog colonies in the largest blocks of grassland habitat, OSMP feels that Boulder open space could potentially support larger numbers of ferruginous hawks (Grassland Plan 2010). Furthermore, according to BCPOS, “maintaining prairie dog populations and continuing to maintain or restore large, contiguous blocks of grassland habitat is achievable on behalf of [ferruginous hawks]” (PDHE 2012:27).

Although OSMP states that grassland habitat on open space land could potentially support a larger number of ferruginous hawks, OSMP does not specify that available habitat could support nesting pairs. The ability of a habitat site to support ferruginous hawk nests depends in large part on the proximity of that site to potential disturbances. Because repeated disturbances may cause ferruginous hawks to abandon active nests, any evaluation of nesting habitat should consider the minimum necessary buffer of the potential nesting area from activities that are likely to disturb the hawks. Colorado Parks and Wildlife recommended that ferruginous hawk nesting areas be at least ½ mile from any potential disturbances, including urban areas and areas of human activity. In their paper, Colorado Parks and Wildlife also cites a study that found ferruginous hawks nesting as far as 8 kilometers from active prairie dog colonies, while still utilizing the colonies. From these two studies one can induce that at a minimum, in order to support ferruginous hawk nests prairie dog colonies must be at least ½ mile from potential disturbances, though a distance of 8 kilometers or more is superior.

This significant difference in recommended buffer zone illustrates the need for careful consideration of nesting habitat location. While there is a wide range in the suggested distance of nesting areas to disturbances, the minimum necessary buffer is ½ mile.

Therefore, one metric for this element would be analyzing the distance between active prairie dog colonies and disturbances, to determine how many colonies are at least ½ mile from a disturbance, and could therefore potentially support breeding ferruginous hawks.

However, this analysis would need to consider the argument that nests that are between ½ mile and 8 kilometers from a disturbance are not guaranteed to succeed, and that with increased buffer comes increased likelihood for nests to succeed. An analysis would also need to consider the number of available nesting areas, to account for potential nest abandonment and new site selection in the following years. It is worth reiterating that OSMP has not explicitly stated that available habitat could potentially support nesting pairs, and that this might not be feasible given existing spacial limitations and increasing urban-driven disturbances.

Can it be applied as a framework element? Why or why not?

Although ferruginous hawks are not known to currently nest in Boulder, the region does fall within the potential nesting range for the hawks. One significant and measurable limiting factor for the potential for ferruginous hawk nesting activity is the distance of active prairie dog colonies from disturbances. Therefore, this element can be analyzed by evaluating whether there are any active prairie dog colonies—or prairie dog areas—that are sufficiently far from disturbances. Using maps provided by OSMP and additional data, this element can be applied as a framework element.

ANALYSIS

Overview

Table 1.0: Metric of analysis, and high and low values, for each framework element.

Framework Element	Metric	High Value	Low Value
Density	Average density on active colonies	Average between 10-55/ha	Average <10/ha or >55/ha
Dispersal	Distance between active colonies	Distance of 2-6km	Distance <2km or >6km
Size	Average colony size	At least 50% of colonies ≥ 10 ha	Fewer than 50% of colonies ≥ 10 ha
Burrowing Owls	Colony size and nesting location	At least 50% of colonies within nest closure areas ≥ 35 /ha	Fewer than 50% of colonies within nest closure areas ≥ 35 /ha
Black-footed ferrets	Colony extent	Colonies ≥ 800 ha	Colonies <800ha
Ferruginous Hawks	Distance from colonies to disturbances	Distance $\geq \frac{1}{2}$ mile (≥ 8 km is ideal)	Distances less than $\frac{1}{2}$ mile

The above chart outlines the framework elements analyzed in this section, the metric of analysis for each element, and the parameters used to define a high or low value.

Numbers and data used to rate the categories that are featured in the framework may be old or incomplete. However, these data still provide enough information to assess the relationship between the element and prairie dogs, and how that relationship does or does not demonstrate the current ecological state of prairie dogs. Throughout this section I point out the data or numbers that are old or incomplete, and discuss the implications in consideration of the element to which the data pertains. I illustrate how the data is relevant despite its age or incompleteness.

This framework is just one component of a large-scale analysis of prairie dogs' ecological value on open space land. It is intended to demonstrate the species' value in

relation to a handful of ecological processes. The analysis of each element includes a rating of that element's value. Those ratings are then used to justify an overall assessment of the current ecological value of prairie dogs on open space land. Additional factors are relevant to prairie dog population and ecosystem integrity and persistence but are beyond the scope of available data. Recommendations for additional data to be collected to do such assessment will be addressed later.

Density

This element is rated based on the average density of active prairie dog colonies on open space land. The metrics for this element were drawn from a number of studies cited above, which suggests an ideal density fluctuating between 10 and 55 prairie dogs per hectare. In order to evaluate this element I draw from data provided in two independent studies (Johnson and Collinge 2004 and Sackett et al. 2011). In particular I suggest reason to believe that average densities today are similar to those reported by Sackett et al. in 2003 and 2004, based on a similar number of acres of active prairie dog colonies, and similar distribution of those colonies. It should be noted that since Sackett et al.'s data collection in 2003-2004, two significant plague epidemics have occurred on open space land, eliminating large percentages of prairie dog colonies. The impact of plague epidemics and density is important although not well understood in this case. However, affected colonies have rebounded in size and extent. Drawing from the same logic used above, density levels have likely rebounded as well. Further analysis of the relationship between plague epidemics and long-term effects on density could provide conclusive data.

Because there were slightly fewer acres of active prairie dog colonies in 2013 and 2014 (the latest two years for which there is available data), and given the conclusion presented above that with decreased acres of active colonies comes an increase in density, I infer that the average density now is slightly higher than that reported by Sackett et al. in 2003 and 2004. That study reported estimated average densities between 11 and 64 prairie dogs per hectare, with an average density of 29/ha. Therefore I determine that the current average density is likely slightly higher than this average, but still within the range of acceptable density as suggested within the analytical framework.

I will also reiterate that the density estimates provided by Sackett et al. were only estimates, gathered by visual counts. Thus, the data is not adequate for irrefutable analysis, but does provide a sufficient estimation that can be used to draw the inferences within this analysis. Therefore, the ecological integrity of prairie dogs on open space land in relation to density is given a high value.

Dispersal

This element is rated based on the distance between active colonies on open space land. The ideal distance is between 2-6km, while distances less than 2km and greater than 6km cannot support successful dispersal, thereby negatively affecting individual prairie dogs, genetic diversity, plant dynamics, and colony dynamics. For the purpose of this evaluation, a “high” ecological value exists when a majority of active prairie dog colonies are between 2km and 6km apart, and when the habitats as well as the dispersal paths are not significantly fragmented so as to prevent successful dispersal.

Figure 5.0 shows active prairie dog colonies in 2015. Looking at this map, one could infer that ample dispersal opportunities are available. However, what this map fails to adequately portray is the significantly fragmented nature of open space habitat. As Knopf and Samson stated, prairie dogs' movement creates a larger functional map than just the areas of active prairie dog colonies. It includes the areas between colonies that prairie dogs must utilize and cross in order to disperse (Knopf and Samson 1994). Figure 6.0 reveals the fragmented nature of prairie dog habitat on open space land. The North, East, and South Grassland Preserves are effectively isolated from each other by private land and major roads and highways, rendering successful dispersal between these areas unlikely at best and impossible at worst.

The large and contiguous nature of the North Grassland Preserve currently provides the best opportunity for dispersal. However, many of the active colonies in this preserve are closer together than the 2km suggested minimum distance, creating an environment where there are actually limited opportunities to disperse to other colonies. The area east of the North Grassland Preserve also contains a significant number of active prairie dog colonies that are spaced in such a way to create dispersal opportunities. In this area, though, many active colonies are located within fragmented parcels of the Grassland Planning Area. The gray shading surrounding these parcels indicates private land, or land not owned by OSMP. Therefore, prairie dogs attempting to disperse in this area may encounter a number of threats including fencing, private landowners who actively eliminate prairie dogs found on their property, increased human activity, and other threats. Colonies located to the north and east of the North Grassland Preserve are

similarly fragmented, significantly limiting the potential dispersal opportunities between these colonies.

Figure 5.0 indicates that the majority of colonies located on open space land are at least 2km and less than 6km from each other. Some colonies are closer together and some colonies are further apart. However, the only area that is likely to support successful dispersal based on the distance between colonies is the North Grassland Preserve, where dispersal is not likely to be interrupted by habitat fragmentation. Although many of the active colonies located on open space land are within the acceptable range to promote dispersal, the fragmented nature of the area negates those benefits. Therefore, dispersal is given a low value.



Figure 5.0: 2015 map showing prairie dog colonies on open space land.
(Data courtesy of Open Space and Mountain Parks)

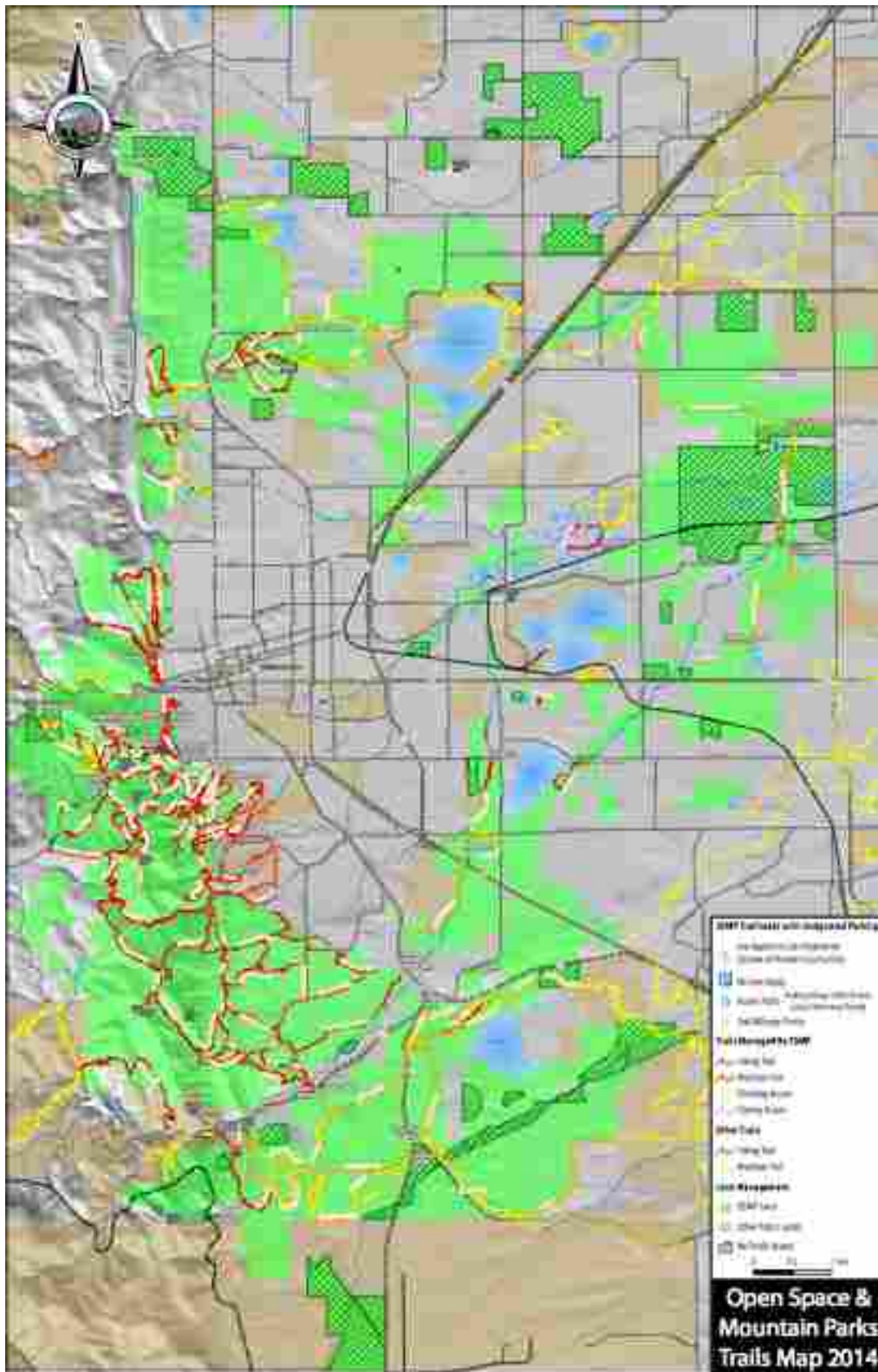


Figure 6.0: Prairie dog colonies in 2014 and the roads, trails, and private land boundaries that can restrict dispersal.
(Map © Open Space and Mountain Parks)

Size

This analysis is made based on average colony sizes on open space land in 2014.

However, as discussed above, this analysis provides only a rating for colony size in one year. While this information helps guide a larger understanding of colony size on open space land, by knowing the rating for one selected year, the rating itself cannot be applied to colony size in all years. The information is valuable for its insight into the current or recent state of prairie dogs and the surrounding ecosystem.

Mapping and GIS data provided by OSMP reveals that in 2014 there were 37 “polygons” 10ha or larger (*See* Figure 7.0). OSMP gathers GIS data annually for over 900 polygons, including area in hectares. However, it is difficult to make a distinction between polygons and actual colonies, particularly when colonies are so close together. Therefore, although these polygons are not necessarily representative of distinct colonies, this data does provide valuable information on the number of *sites* 10ha or greater.

Figure 8.0 shows the location of active colonies, or sites, in 2014. Knowing that in this year there were 37 sites 10ha or larger makes it possible to visually estimate the number of sites within, as well as below, that range. Visual estimates of the number of defined colonies also support this analysis. Based on these estimates, there were at least 75 defined colonies on open space land in 2014, with 37 of those 10ha or larger. Using this estimate, at least 50% of the sites in 2014 were not 10ha or larger. Because fewer than 50% of the colonies are at least 10ha in size, this element is given a low rating. It is also worth noting that while there were 37 sites 10ha or larger, many of those sites were only marginally larger than 10ha, with 29 sites less than 25ha in size.

However, a map of active colonies as of March 2015 shows a significant increase in prairie dog colonies 10ha or larger (*See* Figure 9.0). If this framework element were to be rated as of March 2015, it would therefore be given a high rating. This significant difference in colony size after less than one year reiterates the impermanence of colony boundaries between years and even months, and the constantly fluctuating status of prairie dogs.

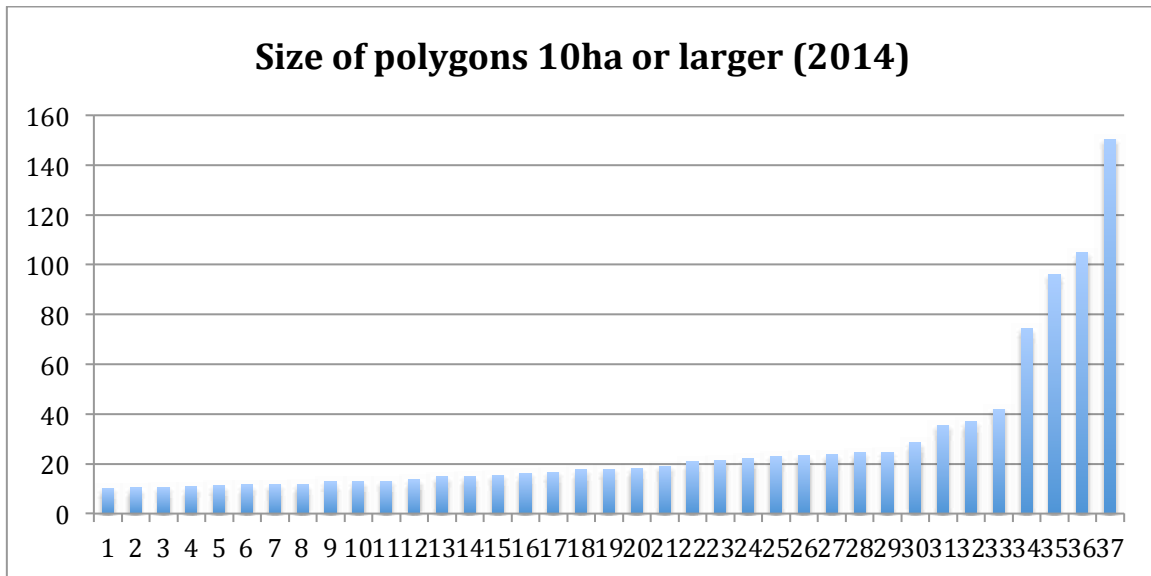


Figure 7.0: Size, in hectares, of the 37 sites 10ha or larger in 2014.
(Date courtesy of Open Space and Mountain Parks)

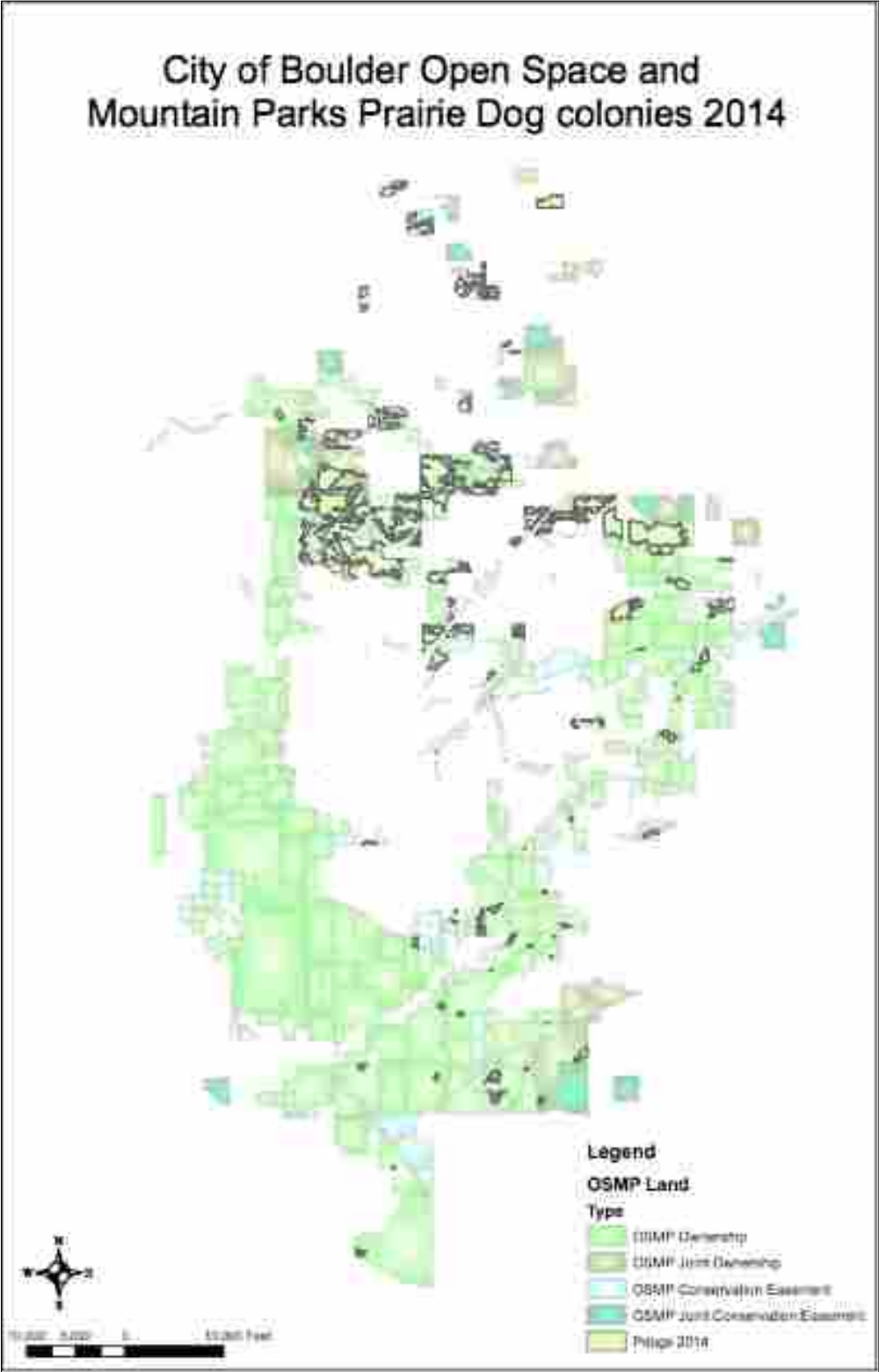


Figure 8.0: Prairie dog colonies on open space land in 2014.
 (Map © Open Space and Mountain Parks)

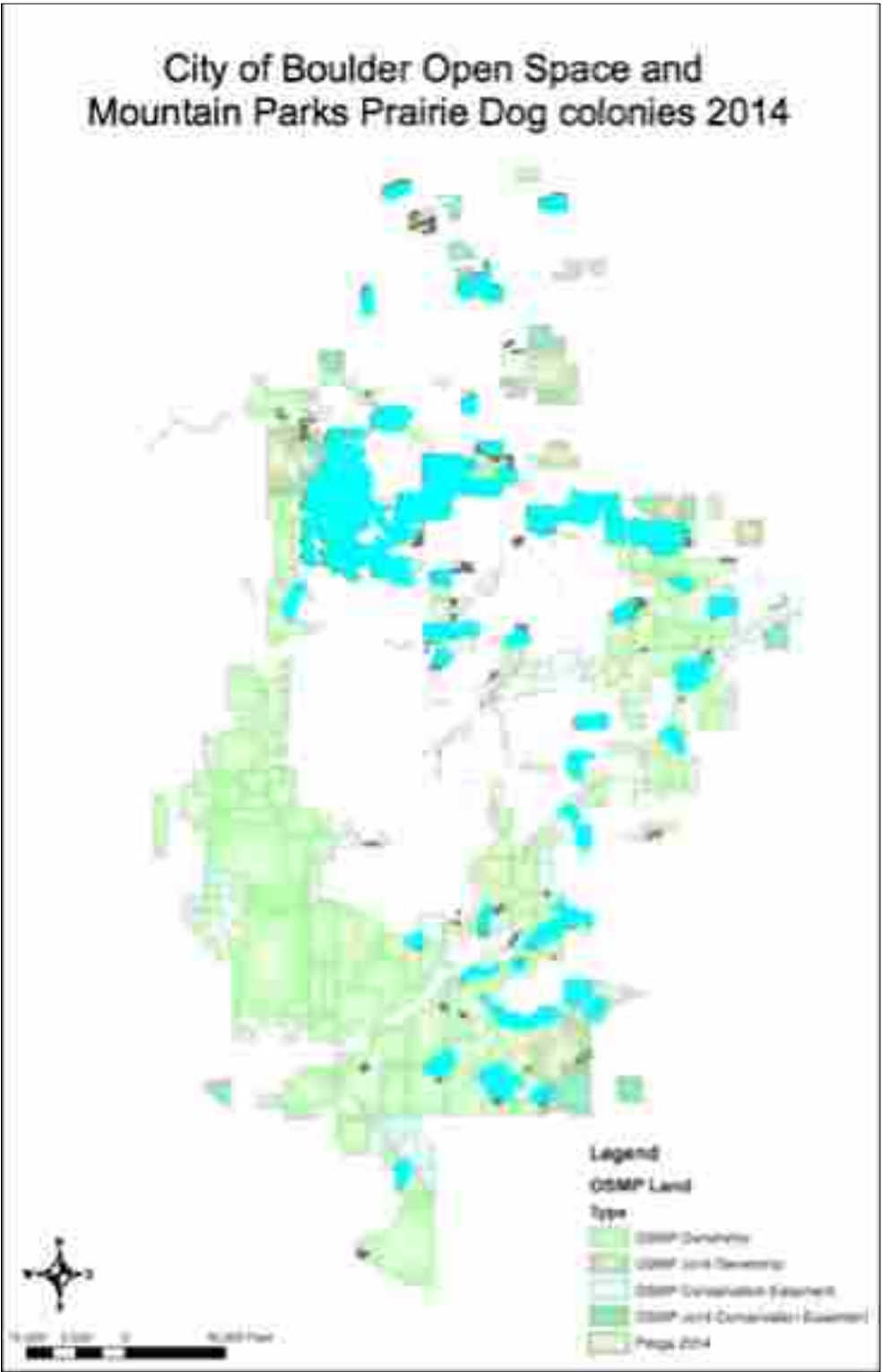


Figure 9.0: Figure 8.0, overlapped with polygons 10ha or larger as of March 2015 (shown in blue).

(Map © Open Space and Mountain Parks)

Burrowing Owls

To analyze the ecological status of prairie dogs in relation to burrowing owls, I look at both the number of colonies that are at least 35ha, as well as the location of nesting closure areas to determine whether there is an overlap between these two factors. Nesting closures in areas without prairie dogs or with small colonies that are unlikely to grow to at least 35ha would indicate a low value.

In 2014 OSMP implemented nesting closures in three areas, two of which share a border and currently create one larger closure site (*See*: Figure 10.0). Two are adjacent to one another, and effectively create one large closure area, while the third area is in the South Grassland Preserve. With the knowledge of nesting closure locations, I can then compare that data to the approximate location of prairie dog colonies that are 35/ha or larger. Based on the data on colony size that was discussed in the Size section above, I can infer that in 2014 there were approximately 7 sites that are at least 35ha on open space land. While the location of these sites is not known, looking at a map of active prairie dog colonies in 2014 can expound approximate locations of these large sites.

This comparison reveals that while one nesting closure area is potentially viable, one has no prairie dogs on it due to a plague outbreak. The sites that are viable are the two located in the East Grassland Preserve, where the two closure sites encompasses a large colony that, based on visual estimation, is at least 35ha.

With only two nesting closure areas that have a 35ha + colony, another area with no significant prairie dog activity, and only seven colonies 35ha or larger, this framework

element could be given a low value. However, further consideration must be given to OSMP's closure site selection process. Closure site locations are entirely based on the locations where owl pairs are observed. Once a pair is observed, a closure is put into place. That closure remains until no owls are observed at the site for three consecutive years. Furthermore, while prairie dog colony location is not considered in nest closure site selection, OSMP does have a policy that any colonies within a nest closure area not be eligible for transition or removal so long as the closure is in place (Swanson, personal communication). Therefore, while site selection may not specifically consider the location of prairie dogs, because site selection is determined by the presence of owl pairs, and because prairie dogs within a closure site cannot be translocated or removed, this framework element is given a high value rating. OSMP allows owl pairs to naturally select their nesting areas and then implements protections accordingly, so any closure areas without the presence of prairie dogs will either experience a rebound of prairie dog populations and remain a closure site, or burrowing owls will not be observed for three consecutive years, and the closure will be lifted.

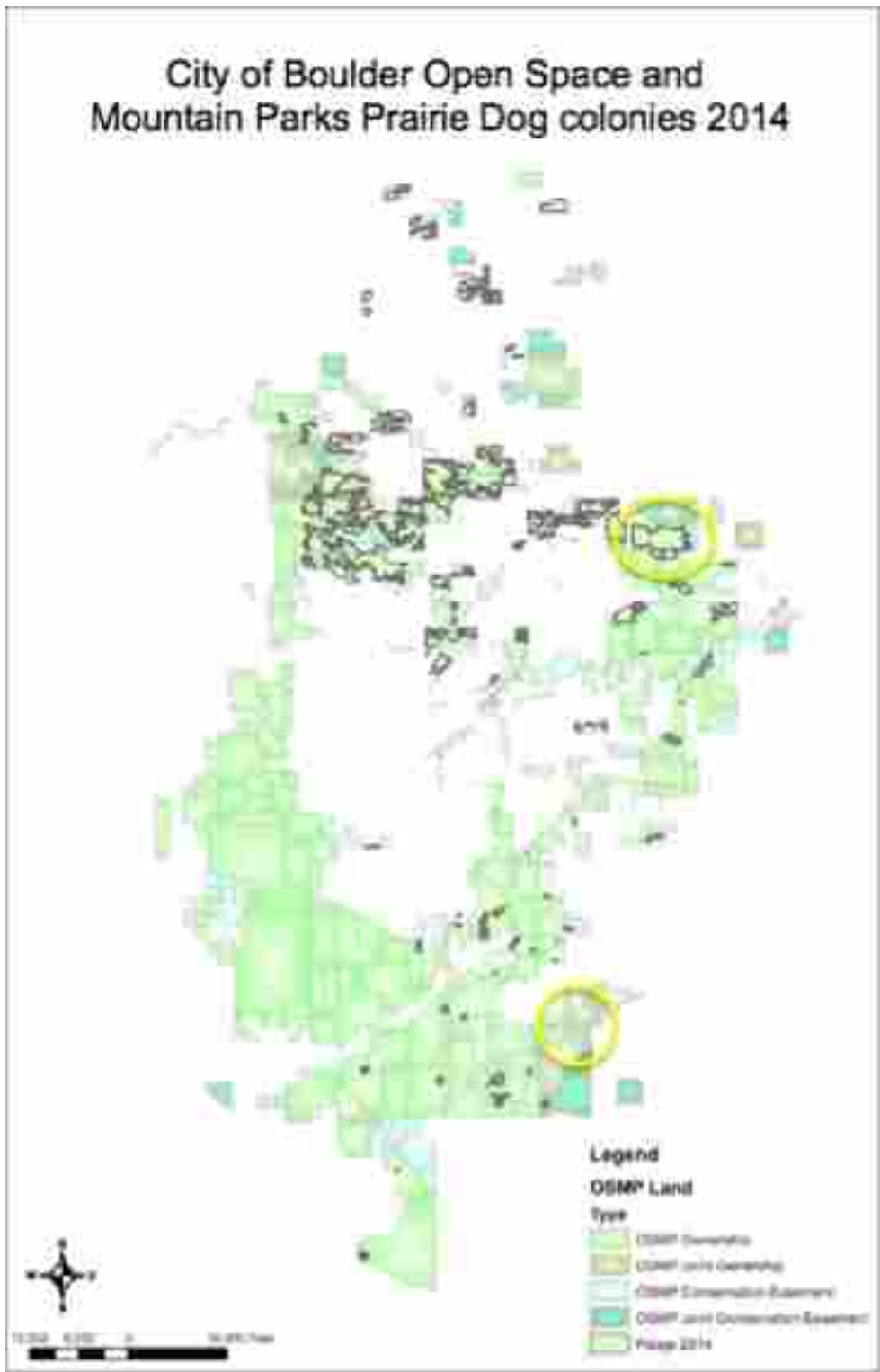


Figure 10.0: Location of burrowing owl nest closure site locations, together with active prairie dog colonies in 2014.
(Map © Open Space and Mountain Parks)

Black-Footed Ferrets

This element is rated based on the availability of at least one colony or closely connected network of colonies that are greater than or equal to 800ha (8 km², or 3.08 mi²), or the potential for a colony or network of colonies of this size on open space land. This can be evaluated using maps published by OSMP on active prairie dog colonies, as well as available prairie dog habitat and conservation areas.

OSMP has evaluated available habitat based on its potential to support prairie dogs, and categorized parcels based on how they will be managed. The categories are “Grassland Preserve,” “Multiple Objective Area,” “Prairie Dog Conservation Area,” “Transition Area,” and “Removal Area.”

Table 2.0: Prairie dog management areas, as outlined by OSMP in 2008.

Framework Element	Management Focus
Grassland Preserve	Conservation of prairie dogs and their associated species in large and ecologically diverse grassland habitat blocks.
Multiple Objective Areas	Conservation of prairie dogs and their associated species is one of multiple management objectives.
Prairie Dog Conservation Areas	Conservation of the prairie dog is the primary management objective; associated species managed opportunistically.
Transition Areas	Conservation of targets other than the prairie dog and associated community takes precedence—removal generally when relocation sites are available.
Removal Areas	Conservation of targets other than the prairie dog and associates incompatible with prairie dogs—management options include immediate removal.

In Figure 11.0, the yellow circles indicate the two areas that are large enough to potentially support a population of black-footed ferrets. While there are prairie dog colonies outside of these circles, these colonies are outside of Grassland Preserve areas, (See Figure 12.0). In 2014 the only Grassland Preserve area with a prairie dog population large enough to support black-footed ferrets was the North Grassland Preserve. The South Grassland Preserve has fewer numbers of prairie dog colonies because of a plague epidemic in 2009 that eliminated colonies in the area almost entirely. As the prairie dog population in this area continues to rebound, however, the area could contain a sufficient prairie dog population to theoretically support black-footed ferrets.

However, the extent of prairie dog colonies is not the only factor to be considered. While there are two areas that could support black-footed ferrets based on the size of the Grassland Preserve areas, Figure 12.0 indicates the further challenge of this objective. The yellow circles again highlight the two Grassland Preserves, while also displaying the boundaries for OSMP's habitat management designations, as well as the maximum extent of prairie dog habitat.

This map shows that although there are Grassland Preserve areas potentially large enough to support a black-footed ferret population, the available prairie dog habitat within these preserves is a limiting factor. Comparing Figure 11.0 to Figure 12.0 shows that in 2014 active prairie dog colonies were located outside of Multiple Objective Areas and Prairie Dog Conservation Areas. Colonies outside of these designated areas are at risk of translocation or eradication. Furthermore, a comparison of the maps shows that even potential prairie dog habitat not constrained by current management designations is a

limiting factor. The maximum extent of colonies in the Grassland Preserves is not contiguous, and particularly within the South Grassland Preserve, accounts for very little total acreage. Therefore, although two Grassland Preserves on open space land may be large enough to support a population of black-footed ferrets, neither preserve can certainly support prairie dog colonies large enough to maintain a black-footed ferret population.

With insufficient available habitat that can be permanently occupied, black-footed ferrets cannot establish in the area. Based on the above determination, the ecological status of prairie dogs on open space land in relation to black-footed ferrets is given a low value.

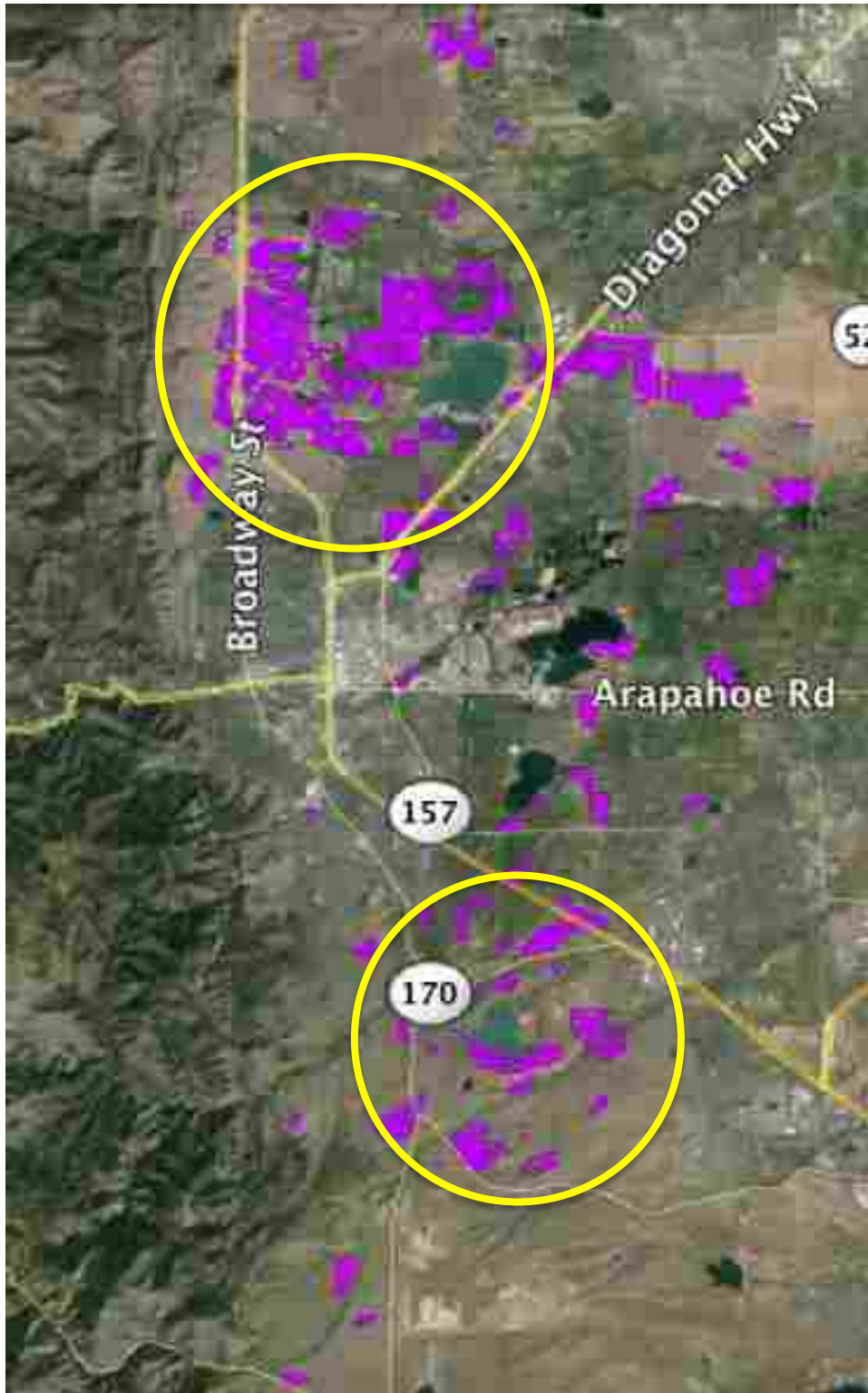


Figure 11.0: Grassland Preserve conservation areas that could potentially support black-footed ferret populations, together with active prairie dog colonies in 2015. (Data provided by Open Space and Mountain Parks)

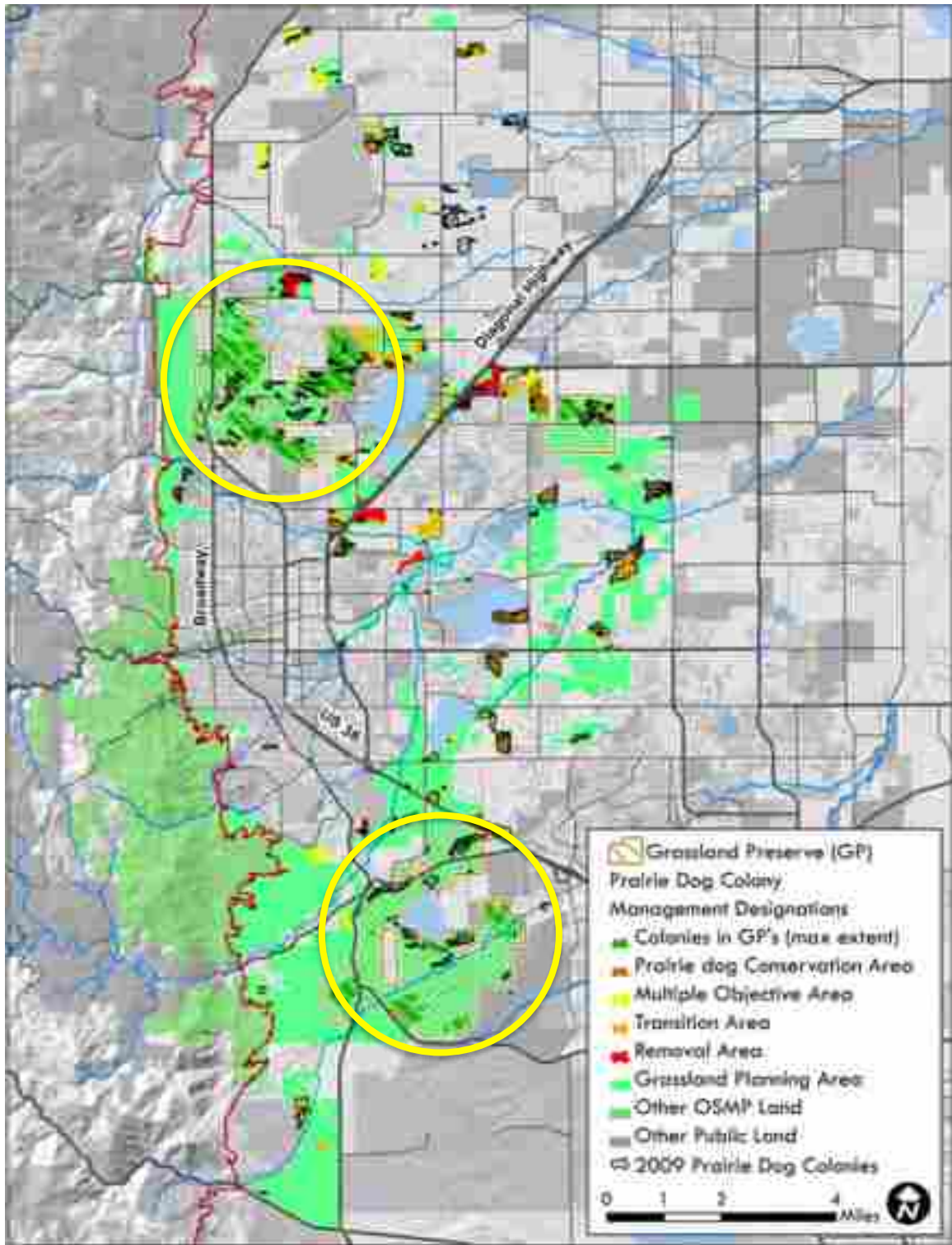


Figure 12.0: Grassland Preserve conservation areas that could potentially support black-footed ferret populations, together with the maximum extent of prairie dog colonies and land management designations in 2008.

(Map © Open Space and Mountain Parks)

Ferruginous Hawks

To evaluate prairie dogs' ecological value in relation to ferruginous hawks, I analyze whether there are colonies $\frac{1}{2}$ mi from a potential disturbance, particularly human-driven disturbances including residential areas, high traffic areas, and recreation. Figure 13.0 represents the two Grassland Preserve areas that are the best opportunities to potential ferruginous hawk habitat on open space, and the location of active prairie dog colonies in 2014.

Figure 13.0 illustrates that the South Grassland Preserve is the best opportunity for ferruginous hawk nesting habitat on open space land, due to the area's size as well as its distance from urban activity. Figure 14.0 also shows how this area is, in theory, large enough to support ferruginous hawk nesting activity, with open space further than $\frac{1}{2}$ mi. from potential disturbances. However, there may not be sufficient prairie dog habitat to support ferruginous hawk nesting activity. As Figure 13.0 shows, in 2014 there were only a few small, scattered active prairie dog colonies on the South Grassland Preserve. Although this area once contained a much higher number of active prairie dog colonies, a plague epidemic between 2008 and 2009 devastated prairie dog colonies in that area.

This points to an issue that open space managers should consider when attempting to identify ferruginous hawk nesting habitat. Cyclical plague epidemics are a natural process and part of long-term prairie dog living dynamics, but when these epidemics occur they frequently wipe out entire areas of prairie dog colonies. Were ferruginous hawks to successfully nest on open space land during a period where prairie dog colonies have large enough to support the hawks, a plague epidemic could, in the matter of only one

year, eliminate the prairie dog colonies in the area where ferruginous hawks may have nested. In the context of open space land, where nesting opportunities are already exceedingly scarce, this can leave ferruginous hawks stranded, resulting in nest abandonment and permanent emigration from the area.

Figure 14.0 illustrates why the extensive multi-use trail system has rendered the North Grassland Preserve unsuitable for ferruginous hawk nesting. The purple boxes indicate the two areas within the North Grassland Preserve that provide the best opportunity for nesting habitat. There may be narrow margins of land within these areas that are $\frac{1}{2}$ mi or greater from a disturbance such as a multi-use trail, road, or other land use. However the extent of potential nesting habitat is not sufficient to be likely to support consistent nesting. Any potential nesting habitat in this area is also constrained by plague dynamics, and the lack of additional nesting sites to support hawk relocation in the event that colonies in the Northern Grassland Preserve are eliminated due to plague.

The ability of prairie dog colonies on open space land to provide nesting and predation opportunities for ferruginous hawks is limited by the proximity of potential disturbances to available prairie dog habitat and potential nesting sites. Nesting potential is further constrained by the lack of additional nest site locations should hawks relocate in the event of a plague epidemic in the area where they have established a nest. Because of these two factors, this element is given a low rating. However, it should be noted that ferruginous hawks currently and are likely to continue utilizing open space land seasonally. The low rating pertains to nesting potential, and the benefits that could be afforded to hawks and prairie dogs if ferruginous hawks were likely to nest on open space land.

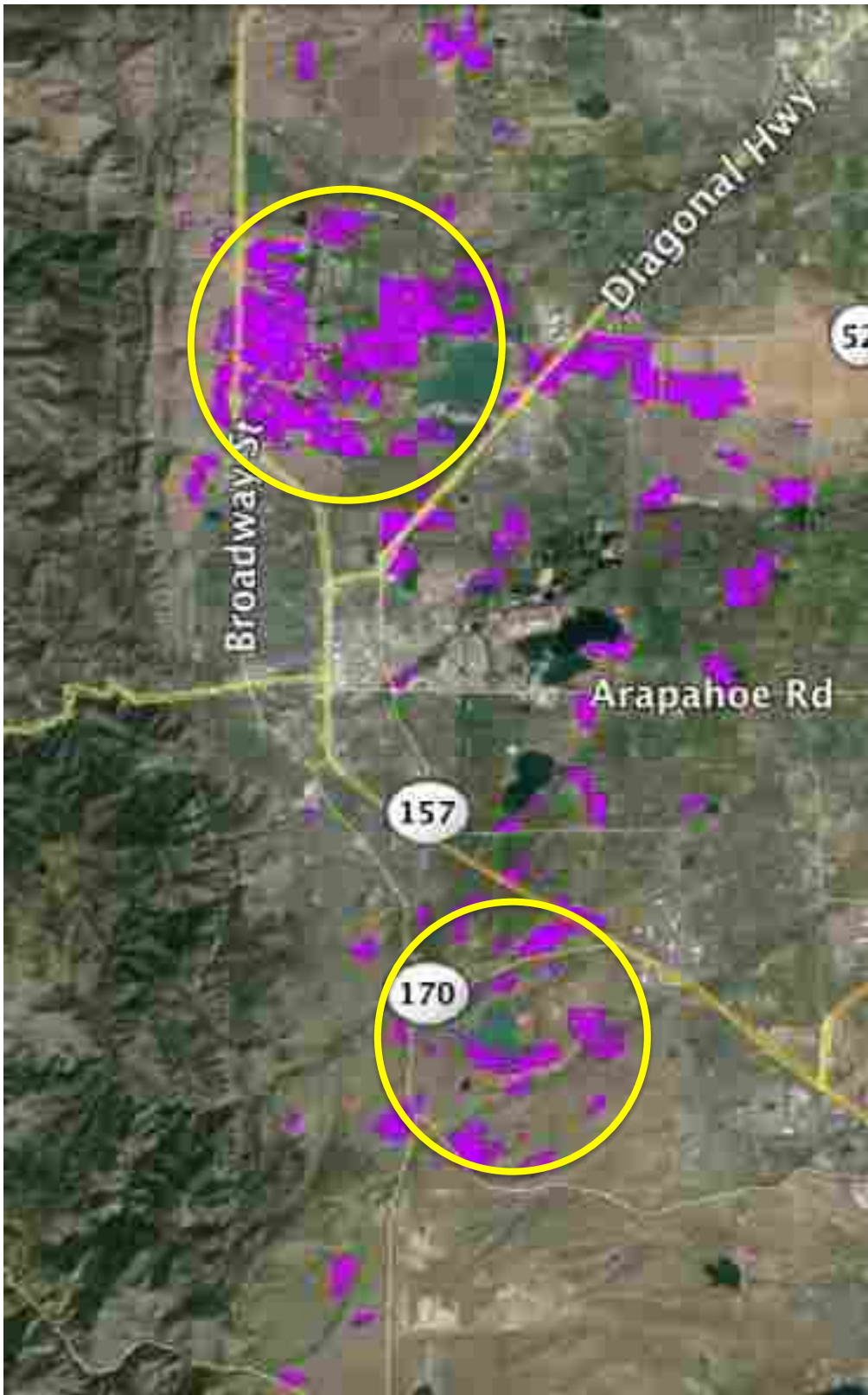


Figure 13.0: Map showing the locations of the two major Grassland Preserve conservation areas and active prairie dog colonies within those areas in 2015. (Data provided by Open Space and Mountain Parks)

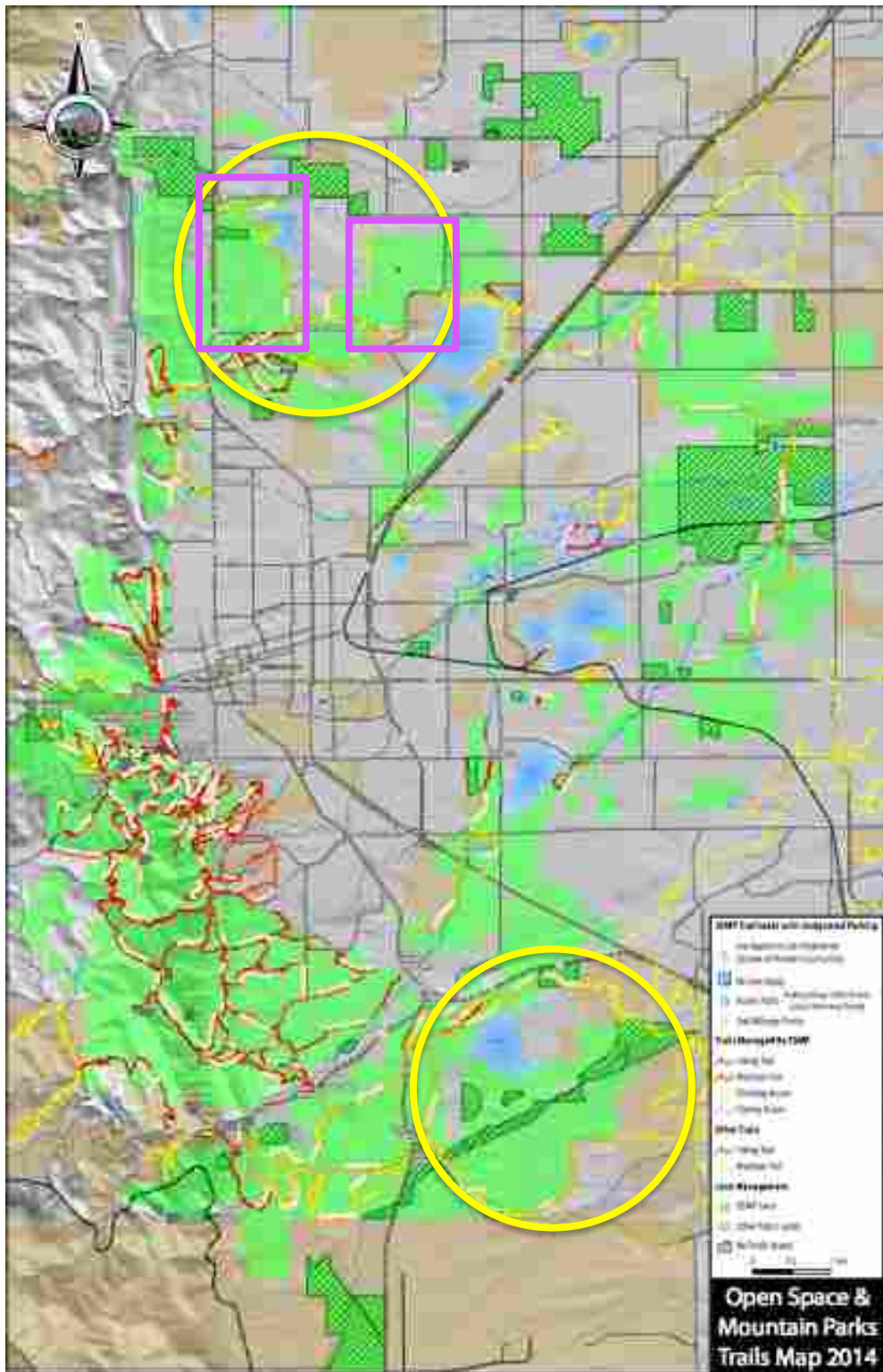


Figure 14.0: Map showing the locations of the two major Grassland Preserve conservation areas and multi-use trail systems within those areas in 2014.
(Map © Open Space and Mountain Parks)

RECOMMENDATIONS

Overview

Table 3.0: Final ratings and recommendations

Framework Element	Rating	Recommendation
Density	High	None. Keep prioritizing the management of other ecosystem processes.
Dispersal	Low	Explore opportunities for collaborative dispersal mitigation.
Size	Low	None. Manage size by managing other ecosystem processes.
Plant Dynamics	None	Gather data on the percent of native and nonnative plant cover on and off active prairie dog colonies.
Burrowing Owls	High	None. Continue to manage nest closure sites based on owl presence and prohibit the transition or removal of prairie dogs within closure sites.
Black-footed Ferrets	Low	Discontinue efforts related to accommodating this species on open space land. Divert resources to analyzing other associated species.
Ferruginous Hawks	Low	None.

Despite the fact that two of the six framework elements analyzed in the Analytical Framework section indicated prairie dogs having a low ecological value in relation to the respective metrics, these results should not be interpreted as a suggestion that efforts surrounding prairie dog conservation and management be abandoned. On the contrary, these results indicate a need to invest more resources into prairie dogs management on open space land. Because prairie dogs are a possible keystone species and significantly affect their ecosystem, it is important to identify management strategies that can benefit prairie dogs and associations including plant dynamics and associated species. Drawing from the above discussion and analysis results, I identify potential strategies and critical gaps in data and formulate recommendations for OSMP moving forward. I then make my

key recommendation: to develop, and implement a collaborative prairie dog management program.

LIVING DYNAMICS

Density

Based on the conclusion drawn in the analysis portion of this paper that the average density of prairie dogs on open space land is within a reasonable range, I do not recommend any changes to how OSMP currently manages for density. Furthermore, personal communication with staff at OSMP has revealed more about the reasoning behind their inability and disinterest in conducting internal studies on density. Density is variable, fluctuating over the whole landscape as evidenced by the wide range of average densities reported at many study sites cited above, average densities within colonies are in constant flux as well. Attempting to obtain baseline information on density would require a tremendous amount of resources—most notably time and money—and would provide little long-term value (Swanson, personal communication). Any data collected would need to be recollected annually, and even then long-term trends will provide little use from a management perspective. To manage density typically means to reduce density, and the common methods of reduction are extermination or removal. Both of these cost further time and money, and strain public relations. I recommend that OSMP continue to not collect data on or manage for density. Rather, I recommend that OSMP continue to prioritize improving dispersal opportunities, and facilitating a study of plant dynamics.

Dispersal

The Analysis section demonstrated the lack of sufficient dispersal opportunities on open space land. Although many colonies are within the acceptable range to theoretically support dispersal, dispersal pathways are fragmented by private land, trails, roads, and other landscape features. These features are permanent fixtures on the landscape—roads are unmovable, private landowners are not required by law to accommodate dispersing prairie dogs, and the multi-use trail system is heavily utilized year-round. Because of this permanence, accommodating dispersal on open space land would require a massive collaborative effort between recreationists, private landowners, and the city and county to develop and adhere to a wide-scale dispersal accommodation program.

Dispersal pathway mitigation options are one option. Much of the literature focuses on dispersal mitigation through prevention, in order to reduce conflict between prairie dogs and surrounding land uses. Barriers such as fences and hay bales restrict prairie dog movement, limiting dispersal. Instead, I recommend that OSMP investigate opportunities to aid dispersal, with the goal to develop a collaborative dispersal mitigation program as part of a comprehensive collaborative management plan. Such a program would require, as stated above, the cooperation of private landowners, city and county officials, citizens, and all other impacted parties.

Size

Colony size is not static. The shape, size, and extent of colonies are constantly changing. While this is true for any ecosystem component, size is particularly challenging to manage for because colony size, while measurable, varies greatly year to year. Some years, colony size is greatly reduced or eliminated in one area. Similarly, as some areas succumb to environmental or human-caused reductions in colony size, other areas may see a marked increase in colony size as colonies take advantage of favorable environmental conditions.

Managing size is exceptionally complex and, because this data can change dramatically from year to year, impractical. However, it is important to look at long-term trends in average colony size to ensure that, generally, colonies exist that are of minimum sizes to support prairie dog colonies and the other ecological functions that prairie dog colonies support. This is important because colony size affects not only all of the other framework elements discussed in this paper, but also the entire relationship between prairie dogs and their ecosystem.

Because colony size cannot practically be managed, but is a critical component of prairie dogs' ecological function, following through with the management recommendations made for the other framework elements will help ensure that size is also successful. For example, nesting trends, native plant cover, and many other factors are all affected by colony size. Success with these other elements will indicate success in colony size trends long-term. Therefore, I recommend that rather than actively managing colony size,

OSMP continue to gather annual data on colony size and extent through mapping, and use the other categories to manage colony size.

PLANT DYNAMICS

OSMP needs to gather data on the percent of native and nonnative plant cover on and off active prairie dog colonies. Prairie dogs affect plant dynamics on active colonies in several ways. Behaviors such as burrowing, grazing, and clipping reduce overall cover but increase the nutrient content in plants. These changes are a part of the ecosystem's natural processes. However, in situations where colonies exist unnaturally such as on open space land, with heavy fragmentation, increased boundedness, and—potentially—high density, these dynamics may change. Colonies that become too dense may reduce plant cover so much that nonnative plants are able to take advantage and overtake native plants. For these reasons I recommend OSMP conduct a study on plant cover on and off colonies. This study could theoretically be conducted in conjunction with an analysis of prairie dog density, but the purpose of this paper is not to suggest specific data collection methods. This point only serves to outline the potential relationship between suggested data collection.

ASSOCIATED SPECIES

Burrowing Owls

OSMP recognizes the close relationship between burrowing owls and prairie dogs. Although OSMP does not consider the presence or lack thereof of prairie dog colonies when implementing a nesting site closure, prairie dogs on site are not eligible for transition or removal, thereby protecting prairie dog populations on closure sites. While

burrowing owl nest success does relate to colony size, OSMP allows burrowing owl presence to determine closure locations, rather than implementing closures in areas that might be determined to be successful nest site locations. I do not recommend any changes to OSMP's current strategy of owls to naturally select nesting areas.

Black-Footed Ferrets

Black-footed ferrets are no longer found in the region and it is not likely that this species can successfully and sustainably return to the open space ecosystem. Because black-footed ferrets require large, active prairie dog colonies, larger than the available area in any one parcel on open space land, restoring this species in this region is not possible.

The absence of black-footed ferrets is not to be overlooked: the species is a main predator of prairie dogs, and helps naturally regulate prairie dog populations. Where prairie dogs persist without black-footed ferrets, overpopulation may become an issue.

On the surface it would seem that converting hundreds of acres of existing grassland habitat into prairie dog conservation areas, creating a landscape where a prairie dog colony could grow to 800ha, in order for OSMP to create habitat suitable for black-footed ferrets. However, it is worth re-emphasizing that prairie dog habitat is made up of a larger functional landscape, one that allows for colony expansion, individual dispersal, and adequate available space to respond to climate, predation, disease, and other threats.

Based on the existing boundaries of open space land, restricted by urban areas, municipal boundaries, and private land, acquiring and developing sufficient habitat—both in direct size and the larger functional landscape—for either of these associated species is not feasible, and therefore I recommend OSMP discontinue efforts to accommodate this

species on open space land. Rather, I suggest that OSMP can divert the resources used to explore black-footed ferret re-introduction to analyze the status of other species closely associated to prairie dogs that currently or are more likely to be found on open space land. As mentioned in the (Ecology) section, with nearly 200 associated species, there is a host of species OSMP can analyze, to develop a more robust understanding of the relationship between prairie dogs and associated species on open space land. I recommend OSMP next analyze mountain plovers. In one study, plovers met more criteria for dependence on prairie dogs than did ferruginous hawks (Kotliar et al. 1999).

Ferruginous Hawks

Ferruginous hawks are not likely to nest on open space land. Few habitat areas that can support active prairie dog colonies are at least ½ mile from human disturbances. Furthermore, ferruginous hawks are exceptionally sensitive to disturbances. Significant or repeated disturbances may cause hawks to abandon nest sites and relocate in other areas. Although there are a selection of small sites that could host both prairie dogs and ferruginous hawk nests, these sites are few in number and there is still a chance of disturbances in these areas. With no nest site alternatives should ferruginous hawks nest on open space land but abandon nest sites due to disturbances, it is not reasonable to attempt to support nesting activity on open space land. Although ferruginous hawks may be found on open space land in the winter, and Boulder is within their potential year-round range, nesting is not likely. Because ferruginous hawks are not likely to successfully establish short- or long-term nesting habits on open space land, I support OSMP's decision not to devote resources to establishing ferruginous hawk nesting activity on open space land.

COLLABORATIVE MANAGEMENT

Although there were 3,052 acres of active prairie dog colonies on open space land in 2014, there is little to no ecological value of 3,052 acres of fragmented habitat. Issues with fragmented habitat have been discussed at length, but to reiterate, fragmented habitat leads to decreased genetic variation, which limits the population's ability to successfully respond to changing conditions. Furthermore, it is important to remember that prairie dogs' movement creates a larger functional map than just the areas of active prairie dog colonies (Knopf and Samson 1994). The number of occupied colonies also changes year-to-year, based on plague, relocation, eradication, natural movement, and other factors. In order to effectively conserve prairie dogs in light of the larger functional map that their movement creates, management must be collaborative.

Collaborative management should involve a number of stakeholders, including but not limited to OSMP, BCPOS, OSMP land lessees, landowners within city limits whose property lies within current or potential prairie dog dispersal paths, recreationists who utilize areas where prairie dogs may live or disperse across, local government agencies; and nonprofit organizations whose missions and goals relate to prairie dog and Front Range conservation. Ideally, collaboration would extend beyond the boundaries of open space land to include, at a minimum, stakeholders throughout Boulder County (This recommendation again relates back to the larger functional map that prairie dog movement creates. Creating space for stakeholder input and participation from parties within and peripheral to city and open space boundaries will increase the likelihood that long-term management plans succeed, as individual prairie dogs and colonies naturally move between the human-generated borders that nature does not follow. With appropriate

parties at the table representing an appropriate scale of prairie dogs' functional range, stakeholders can then work together to develop comprehensive conservation strategies that support prairie dog dispersal and increase dispersal success.

ADDITIONAL CONSIDERATIONS

Adaptive Management

The analysis, data collection, and collaborative management recommendations made above will help OSMP managers assess the overall ecological value of prairie dogs and develop a more sustainable, inclusive management plan. However, many of the data discussed in this paper and data referenced in the Grassland Plan are based on the historical state of prairie dogs and their associations in the region. It is important to recognize the capacity for an ecosystem to shift over time. Managing prairie dogs based on knowledge regarding historical associations may not itself lead to successful conservation long term. One example is the historically significant presence, but lack of current and future occurrence, of black-footed ferrets on open space land. Though I will not claim that Boulder's open space is a novel ecosystem (this claim would require more concentrated and comprehensive ecosystem analyses), open space land and its ecosystems have been radically altered in recent decades by urbanization, increased human presence, and the resulting changes in natural processes. Roads, trails, and urban areas have increasingly fragmented Front Range habitats, and species dynamics have shifted due to predator management programs and the conversion of prairie habitat to agricultural land. As a result, the overall ecological dynamic of the region is not and will never again truly reflect the historical ecosystem, as it existed before urbanization.

Therefore, it is critical that OSMP incorporate adaptive strategies into any current and future management plans, in order to continually address the ecosystem's current state.

CONCLUSION

OSMP should work to develop a collaborative management plan that is based on ecosystem wholeness, looking at the status and needs of prairie dogs, as well as species that currently affect or are affected by prairie dogs, on open space land. Collaborative management can help address some of the current limitations of prairie dog management on open space land, including limited dispersal opportunities. Facilitating better dispersal opportunities is the recommended first step towards developing more sustainable management practices that will lead to improved long-term ecosystem health.

In summary, I recommend OSMP take the following steps:

1. Gather data on the status of native and nonnative plant dynamics on and off colony to better understand the current relationship between prairie dogs and native plants.
2. Redirect resources away from evaluating the potential for black-footed ferret reintroduction on open space land, and instead analyze the relationship between prairie dogs and other key associated species. I recommend beginning with an analysis of the current relationship between mountain plovers and prairie dogs.
3. Begin working towards a collaborative management plan. The first step is to generate a list of potential stakeholders, and open up lines of dialogue to gauge interest, assess shared values and concerns, and understand how prairie dogs

currently impact stakeholders. The list of stakeholders may include but should not be limited to:

- Open Space and Mountain Parks
- Boulder County Parks and Open Space
- OSMP land lessees
- Landowners
- Recreationists
- Local government agencies
- Nonprofit organizations

Gathering the data recommended above will provide OSMP with more robust information regarding the current overall ecological value of prairie dogs on open space land. Moving towards a collaborative management scheme can help OSMP develop management practices that encompass both ecological and social needs, leading to a management system that increases the value of prairie dogs on open space prairie habitat. This can result in improved overall ecosystem health, which can help OSMP achieve its mission, to “[preserve] and [protect] the natural environment and land resources that characterize Boulder. We foster appreciation and use that sustain the natural values of the land for current and future generations.”

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